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ROCK WEATHERING STUDY
IN THE IDAHO BATHOLITH

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Professor and
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DEPARTMENT OF CIVIL ENGINEERING
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by

Department of Civil Engineering

Howard University, Washington, D.C.

for

Intermountain Forest and Range Experiment Station

Forest Service, U.S. Department of Agriculture

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INTRODUCTION

Previous experience has shown that geological and groundwater conditions, in consort with steep slopes, friable soils, climatic conditions, and the works of man have combined to produce conditions in the Idaho Batholith which present a threat to its ecology. The U.S.D.A. Forest Service has been concerned with this problem for some time. This concern has manifested itself in the formation of a Batholith Research Steering Committee and the funding of both "in house" and outside research.

Howard University has actively participated, on behalf of the Forest Service, in basic research to better understand the fundamental properties of the soils and rocks found in the Idaho Batholith. The first study, began in 1970, was concerned with understanding the basic properties and behavior of the soils and rocks of the Batholith[3]. Subsequently, in 1973, the research reported herein was begun. This study is an extension of the 1970 research and investigated the effects of simulated environmental conditions on the rate of weathering of rocks of the Batholith.

PURPOSE AND SCOPE

The purpose of the proposed study was to establish the relative effect of climatic factors on the deterioration of rock found in the Idaho Batholith. Two simulated climatic conditions were investigated -- alternate wetting and drying and alternate freezing and thawing. Initial rock conditions represented a range in rock weathering and fracturing classes prevalent in the Batholith.

The effect of environmental cycling on rock weathering was ascertained by use of the sonic velocity test, i.e., decreases in sonic velocity with time, after the start of environmental cycling, would indicate the rate of weathering of the rock under the imposed conditions.

GEOLOGY

The rock of the Idaho Batholith is characterized by various granitic rocks of late Jurassic or early Cretaceous age. Differences in rock properties, tectonic events, and climate, throughout geologic time, have resulted in the formation of various landscapes. For example, the following major land types have been observed in the Zena Creek area:[4]

1. Strongly glaciated granitic lands
2. Peri-glacial, granitic lands
3. Alluvial lands
4. Stream cut, decomposed granitic lands
5. Complex lands - combinations of the land types given previously,

The Zena Creek area is a relatively small part of the Idaho Batholith but is representative of the variety of landforms which can be found within it.

Another point of importance is that rocks which form the Batholith have significant variations in properties. These variations are the result of differences in mineralogical content which produce differences in weathering rate and differences in the secondary minerals formed. Rocks which are fractured and close to the surface have greater weathering rates.

Climatic changes can be observed as one increases in elevation.

SITE SELECTION AND LOCATION

In order to optimize the benefits from site selection, the expertise of personnel of the U.S.D.A.'s Forestry Sciences Laboratory at Boise (FSLB) was utilized. They are very familiar with geological conditions in the area and

their assistance was of great value.

During the initial stages of site selection, FSLB personnel toured the forests located in the Idaho Batholith and made preliminary site selections. Subsequently, final site selections were made during a tour of the Batholith by personnel representing both FSLB and Howard University. A total of 12 sites (see Fig. 1) were finally selected with the intention of utilizing the first ten sites, in numerical order of selection, from which adequate samples could be obtained for laboratory testing.

The aforementioned 12 sites were chosen along a single logging road within the Gold Fork Watershed. These sites provided a reasonable distribution of rock weathering classes found within this area. Rock weathering classification was assigned to each site based on Reference 2.

SUBSURFACE EXPLORATION AND SAMPLING

Subsurface exploration at each site was performed by truck mounted, rotary, drill rigs, utilizing diamond core bits, to obtain samples of the rocks. The core drilling was performed in accordance with ASTM Test Designation D2113[1]. An attempt was made to obtain ten feet of rock core at each site sampled, with a significant portion of the samples obtained being of sufficient length to test in the laboratory. At certain boring locations, it was not possible to obtain samples of a length adequate for testing due either to the fracture pattern in the rock and/or the breakdown of the rock during the drilling process.

NX-size (2.14 in. diameter) cores were obtained from the field subsurface investigation. Once samples were obtained, they were immediately encapsulated, to minimize moisture loss, and stored pending shipment to Howard University for testing.

LABORATORY PROCEDURES AND TESTING

The NX-size core samples, subsequent to arrival at Howard University, were cut to the appropriate size for testing, with a diamond-bladed saw, to obtain right cylindrical samples. The ends of each sample were then smoothed with a lapping machine in order to facilitate testing. Each sample so prepared was visually examined to ascertain any defects which might have a bearing on the performance of a test specimen.

Hardness Tests. The hardness of each specimen was determined by means of a scleroscope, manufactured by the Shore Instrument and Manufacturing Company. The Shore Scleroscope is a nondestructive, hardness testing device which indicates relative hardness by the height of rebound of a small diamond-pointed hammer dropped vertically onto the surface of a sample from a height of approximately 10 inches. The hammer falls vertically within a closed-bore glass tube. Air pressure, supplied by hand actuation of a rubber bulb, operates a catch which releases the hammer. The height of the rebound is read from a scale of 0-140 divisions.

A total of 20 readings, spaced at equal intervals around the circumference of the circle, were taken along the sides of the specimens, at each location, for a total of forty (40) readings per specimen. In addition, twenty (20) readings each were taken along each of two mutually perpendicular diameters, on each end of each specimen, for a total of 40 readings.

The average of the 80 readings, for each specimen, was denoted as the hardness of that particular sample.

Sonic Velocity Tests. Standard pulse techniques were used for the determination of the sonic velocity for the rock specimens while the latter were subjected to a relatively low axial stress. The technique involved the generation of a short-duration, stress pulse of low amplitude, at one end of the specimen,

and accurately measuring the time taken for the arrival of the first recognizable energy pulse at the opposite end. The velocity, V_p, which is the velocity of a dilatational wave in an unbounded medium, or the bulk compressional velocity, is then computed by simply dividing the length of the specimen by the measured travel time.

For each specimen, an attempt was made to obtain sonic velocity measurements at nominal stress levels of approximately 0, 110, 330, and 660 psi. In most instances, it was impossible to determine the sonic velocity at the zero stress level.

Freeze-Thaw-Tests. Chosen specimens from each site were subjected to alternate cycles of freezing and thawing -- 24 hours each of freezing and thawing. During the freezing cycle the specimens were placed in a freezing cabinet and subjected to an ambient temperature of $-10^{o}F$ ($-23^{o}C$). Prior to placement of the specimens in the freezing cabinet, saturated cotton was placed between the specimens and carriers in which the specimens rested while being subjected to freeze-thaw testing.

Following 24 hours of subjection to freezing temperatures, the temperature in the freeze-thaw cabinet was raised to $70^{o}F$ ($21^{o}C$). Free water was made available to the cotton under the specimens to permit them to absorb water by capillary action during the thawing period.

The rate of deterioration of the samples under repeated freeze-thaw cycles was evaluated by sonic velocity tests. Testing occurred at the end of the thaw cycle. Prior to the start of each freeze cycle, the samples were briefly immersed in water.

Wet-Dry Tests. Chosen specimens from each site were also subjected to alternate cycles of wetting and drying. The samples were submerged in potable water at room temperature for a period of 5 hours and removed. The specimens

were then placed in an oven at $160^{o}F$ ($71^{o}C$) for 42 hours and removed.

Specimens were subjected to sonic velocity testing, after a designated number of cycles of alternate wetting and drying, at the end of the drying cycle.

Unconfined Compression Tests. Following the termination of environmental cycling, the samples which remained were subjected, to failure, to unconfined compression testing. The unconfiend compression tests were performed in accordance with ASTM Test Designation D 2938.1

Unit Weight Determinations. Each sample, both prior to environmental testing and, where possible, at the termination of testing, were subjected to unit weight determinations. The latter were made under the assumption that the volume of the specimens did not change with time. The aforementioned assumption, it is realized, was not valid but it was felt that by ignoring the error the resulting unit weight determination, when compared with the initial value, would give an indication of the weight loss which occurred during environmental cycling.

PRESENTATION OF DATA

The data from this study has been summarized in the form of tables and Tables 1a. and 1b. summarize the initial and final weathering classifications of the rock samples utilized in this study. It should be noted that the initial classifications were based on evaluation of all the rock core obtained from each boring. However, the final classifications were based on an assessment of each individual sample subjected to environmental testing. This difference is important since the rock weathering classification sometimes varried over the length of sample obtained from a boring.

Table 2 presents a summary of hardness, unit weight, and unconfined compressive strength data for all specimens tested. These data have been subdivided into the results from Wet-Dry Tests (Table 3) and Freeze-Thaw Tests (Table 4).

Table 1.a. Initial Weathering Classifications

Bore Hole	Depth ft.	Classification
1	1 - 6	80% Class 1, 20% Class 2
1	6 - 12	80% Class 1, 20% Class 2
2	0 - 5	2
2	5+	3
3	1 - 6	4 approaching 5
3	6 - 11	2; 10% Class 3
4	0 - 5	50% Class 3; 50% Class 4
	5+	4
5	1 - 11	2
6	7 - 14	50% Class 5; 50% Class 6
7	0 - 2	3
	2 - 6	3
	6+	4
8	3 - 13	5
9	7 - 9	5
	9 - 17	7
10	all	5
11	1 - 6	1 (microgranite fabric; some pegmatite finegrained)

Table 1.b. Comparison of Initial and Final Weathering Classifications

Bore Hole	Sample No.	Classifications Initial	Classifications Final	Remarks
1	1	1 & 2	2	
	2	1 & 2	2	
	3	1 & 2	1	Failed along fracture in compression test
	5	1 & 2	2	
	6	1 & 2	2	few iron stains
	7	1 & 2	2	fine grained-hint of gneissic fabric
	8	1 & 2	2	failed along fracture in compression
	9	1 & 2	2	
	10	1 & 2	2	
	11	1 & 2	2	few iron stains but all feldspars are opaque; lower mechanical strength than other Bore Hole 1 samples
2	1	2	2	failed along fracture in compression test
	2	2	3	
	3	2	2	aplitic appearance, feldspars strained (from test?)
	4	2	2	aplitic appearance, few iron stains, feldspars appear strained
	5	3	3	aplitic appearance
	6	3	3	
	7	3	2	
3	1	4-5	5	heavily iron stained
	2	4-5	4	heavily iron stained
	3	2 & 3	2	heavily iron stained, hint of gneissic fabric, evidence of alteration but quite hard
	4	2 & 3	3	
	5	2 & 3	3+	
4	1	3-4	1 & 5	some pegmatite on end of core in Class 1, rest is 5
	2	3-4	4	
	3	3-4	5	
	5	3-4	4	
	8	4	4	
	10	4	4	
	11	4	3	few iron stains

Table 1.b. (cont.)

Bore Hole	Sample No.	Classification Initial	Classification Final	Remarks
5	1	2	3	
	4	2	3	
	7	2	3	
	8	2	2	
	9	2	3	
	10	2	3	few iron stains, feldspars milky
	11	2	3	
7	1	3	3	
	1a	3	4	
	2	3	4	few iron stains
	4	4	4	
	4	4	4	
	6	4	4	few iron stains
8	1	5	5	
	2	5	5	
	3	5	6*	failed along a fracture (*this rock is class 5-6 borderline)
9	2	5	-	sample disentegrated to grus
	3	5	6	
10	1	5	7	hydrothermally altered. contains numerous class seams; schistose fabric
	2	5	5	
	4	5	7	similar to Sample 1
11	1	1	2	aplitic fabric
	2	1	2	aplitic
	3	1	2	aplitic, failed along a mica seam
	6	1	4	
	7	1	2 & 3	some pegmatite in sample is class 2, rest is 3
	8	1	1	
	9	1	3	

Table 2. Summary of Hardness, Unit Weight, and Unconfined Compressive Strength Data

Boring No.	Sample No.	Avg. Hardness		Unit Weight, Pcf		Remarks	
		Initial	Final	Initial	Final	Strength q^{u} (psi)	Test Type
1	1	71.5	73.2	165.3	165.1	7278	W-D
	2	73.7	79.7	165.6	165.1	10,673	F-T
	3	69.2	-	164.6	-	2574	-
	5	69. 5	69.7	165.4	165.	10,015	W-D
	6	72.2	75.0	165.5	165.3	5,191	F-T
	7	74.1	76.1	164.5	-	7,879	Control
	8	75. 4	76.4	164.1	164.0	10,391	F-T
	9	82.0	80.7	163.5	163.3	12,424	W-D
	10	83.0	81.7	165.0	164.8	7,181	F-T
	11	83.2	78.9	163.3	160 .2	5,234	W-D
	12	77.8	-	165.0	-		
	Avg.	75.	76.8			7,884	-
2	1	73.5	68.6	164.4	163.9	5,561	W-D
	2	72.3	76.0	162.7	162.7	8,540	Control
	3	79.1	80.5	159.9	159. 8	7,662	W-D
	4	82.7	84.2	163. 1	163.0	13,062	F-T
	5	79.7	81.2	162. 8	162.7	6,997	F-T
	6	77.6	77.1	159.8	159.7	8,314	W-D
	7	81.4	81.4	163.3	163.2	14,144	F-T
	Avg.	78.0	78.4	162. 3	162.1	9,183	-
3	1	71. 5	74.4	164.7	164.5	9611	F-T
	2	66.7	68.7	164. 0	163.7	7189	W-D
	3	69. 8	70.6	162.9	162.3	6985	W-D
	4	67. 0	69.0	163. 5	163. 3	5605	W-D

Boring No.	Sample No.	Avg. Hardness Initial	Avg. Hardness Final	Unit Weight, Pcf Initial	Unit Weight, Pcf Final	Remarks Strength qu (psi)	Remarks Test Type
3	5	67.0	68.4	163.1	162.0	7484	F-T
	Avg.	68.4	70.2	163.6	163.2	7375	-
4	1	31.6	36.4	155.0	153.4	2769	W-D
	2	33.3	35.9	157.9	157.5	3163	F-T
	3	37.5	40.8	157.6	157.5	3590	F-T
	5	29.9	41.4	158.0	157.6	2704	Control
	8	26.8	33.0	157.2	156.6	2642	W-D
	10	38.2	48.5	160.0	159.2	3259	F-T
	11	36.9	39.4	159.0	156.0	2804	W-D
	Avg.	32.4	39.3	157.8	156.9	2990	-
5	1	54.6	60.3	163.0	162.6	6955	W-D
	4	55.4	64.0	163.8	163.5	5825	F-T
	7	59.8	72.3	164.3	164.3	9032	Control
	8	64.1	69.0	164.5	164.3	7746	F-T
	9	65.8	71.9	165.3	165.1	9890	W-D
	10	56.9	65.0	163.7	163.4	6271	F-T
	11	55.9	-	164.4	164.1	7615	W-D
	Avg.	58.9	67.1	164.0	163.9	7619	-
7	1	51.5	54.4	162.6	162.5	4872	W-D
	1	59.6	65.6	162.1	161.5	5401	F-T
	2	51.1	62.7	161.4	161.0	4763	W-D
	4	31.4	32.7	157.4	155.8	1149	W-D
	4	45.0	44.7	160.4	159.9	3467	F-T
	6	42.4	48.3	160.8	160.2	3607	Control
	Avg.	46.8	48.6	160.8	160.2	3877	-

Boring No.	Sample No.	Avg. Hardness Initial	Avg. Hardness Final	Unit Weight, Pcf Initial	Unit Weight, Pcf Final	Remarks Strength qu(psi)	Remarks Test Type
8	1	31.3	34.1	157.6	-	2376	Control
	2	18.0	24.4	-	-	312	-
	3	21.2	-	147.1	-	645	-
	Avg.	23.5	29.2	152.3	-	1111	-
9	1	13.1	-	-	-	-	-
	2	17.4	-	139.2	-	-	-
	3	32.5	-	-	-	-	-
	Avg.	21.0	-	139.2	-	-	-
10	1	13.7	-	154.2	-	-	W-D
	2	13.1	-	146.4	-	-	-
	3	10.6	-	144.0	-	-	W-D
	4	8.8	-	139.7	-	-	-
	5	12.7	-	-	-	-	-
	Avg.	11.8	-	146.1	-	-	-
11	1	68.1	-	162.0	-		
	2	66.1	73.9	160.6	161.1	10,844	F-T
	3	63.2	-	160.6	160.6	-	W-D
	6	47.8	57.1	159.1	158.7	5499	F-T
	7	47.0	49.3	157.3	156.7		
	8	53.0	-	158.7	158.5	-	-
	9	51.9	59.7	158.5	-	5498	F-T
	Avg.	56.7	60.0	159.5	159.1	-	-

Table 3. Summary of Hardness, Unit Weight, and Unconfined Compressive Strength Test Data -- Wet-Dry Tests

Boring No.	Sample No.	Avg. Hardness Initial	Avg. Hardness Final	Unit Weight, Pcf Initial	Unit Weight, Pcf Final	Remarks Strength qu(psi)	Remarks Test Type
1	1	71.5	73.2	165.3	165.1	7278	W-D
	5	69.5	69.7	165.4	165.1	10,015	W-D
	9	82.0	80.7	163.5	163.3	12,424	W-D
	11	83.2	78.9	163.3	160.2	5,234	W-D
	Avg.	76.5	75.6	164.3	163.4	8738	-
2	1	73.5	68.6	164.3	163.9	5,561	W-D
	3	79.1	80.5	159.9	159.7	7,662	W-D
	6	77.6	77.1	159.8	159.6	8,314	W-D
	Avg.	76.6	75.4	161.3	161.1	7179	-
3	2	66.7	68.7	164.0	163.7	7189	W-D
	3	69.8	70.6	162.9	162.3	6985	W-D
	4	66.9	69.0	163.5	163.3	5605	W-D
	Avg.	67.8	69.4	163.4	163.1	6593	-
4	1	31.6	36.4	154.0	153.4	2769	W-D
	8	26.8	33.0	157.2	156.6	2642	W-D
	11	36.9	39.4	159.0	156.0	2804	W-D
	Avg.	31.7	36.3	157.1	155.3	2738	-
5	1	54.6	60.3	163.0	163.0	6955	W-D
	9	65.8	71.9	165.3	165.0	9890	W-D
	11	55.9	-	164.4	164.1	7615	W-D
	Avg.	58.8	66.1	164.2	164.0	8153	-

Boring No.	Sample No.	Avg. Hardness Initial	Avg. Hardness Final	Unit Weight, Pcf Initial	Unit Weight, Pcf Final	Remarks Strength qu(psi)	Remarks Test Type
7	1	51.5	54.4	162.6	162.5	4872	W-D
	2	50.4	62.7	161.4	161.0	4763	W-D
	4	31.4	32.7	157.4	155.8	1149	W-D
	Avg.	44.4	49.9	160.5	159.8	3595	-
10	1	13.7	-	154.2	-	-	W-D
	3	10.6	-	144.0	-	-	W-D
	Avg.	12.1	-	149.1	-	-	-
11	3	63.2	-	160.6	160.6	7896	W-D
	7	47.0	49.3	157.3	156.7	2584	W-D
	8	53.0	-	158.5	158.4	9911	W-D
	Avg.	54.4	49.3	158.8	158.6	6797	-

Table 4. Summary of Hardness, Unit Weight and Unconfined Compressive Strength Data -- Freeze-Thaw Tests

Boring No.	Sample No.	Avg. Hardness Initial	Avg. Hardness Final	Unit Weight, Pcf Initial	Unit Weight, Pcf Final	Remarks: Strength qu(psi)	Remarks: Test Type
1	2	73.7	79.7	165.2	165.1	10,673	F-T
	6	72.2	75.0	165.4	165.3	5,191	F-T
	8	75.4	76.4	164.1	163.9	10,391	F-T
	10	83.0	81.7	165.0	164.8	7,181	F-T
	Avg.	76.1	78.2	164.9	164.8	9657	-
2	4	82.7	84.2	163.1	162.9	13,062	F-T
	5	79.7	81.2	162.8	162.7	6,997	F-T
	7	81.4	81.4		163.2	14,144	F-T
	Avg.	81.3	82.3	163.1	162.9	11,401	-
3	1	71.5	74.4	164.7	164.5	9611	F-T
	5	67.0	68.4	163.1	162.0	7484	F-T
	Avg.	69.2	71.4	163.9	163.2	8548	-
4	2	33.3	35.9	157.9	157.5	3163	F-T
	3	37.5	40.8	157.6	157.4	3590	F-T
	10	30.6	48.5	160.0	159.2	3259	F-T
	Avg.	33.8	41.7	158.5	158.0	3337	-
5	4	55.4	64.0	163.8	163.5	5825	F-T
	8	64.1	69.0	164.5	164.3	7746	F-T
	10	56.9	65.0	163.7	163.3	6271	F-T
	Avg.	58.8	66	164.0	163.7	6614	-
7	1	59.6	65.6	162.1	161.5	5401	F-T
	4	45.0	44.7	160.4	159.9	3467	F-T
	Avg.	52.3	55.2	161.3	160.7	4434	-

Table 4 (cont)

Boring No.	Sample No.	Avg. Hardness Initial	Avg. Hardness Final	Unit Weight, Pcf Initial	Unit Weight, Pcf Final	Remarks Strength qu(psi)	Remarks Test Type
11	2	66.1	73.9	161.2	161.1	10,844	F-T
	6	47.8	57.1	159.1	158.7	5499	F-T
	7	47.0	49.3	157.3	156.7	5498	F-T
	9	51.9	59.7	158.5	158.0	5498	F-T
	Avg.	53.2	63.6	159.0	158.6	7280	-

Sonic test data, at a stress level of approximately 1000 psi, are summarized in Figures 1 to 15, inclusive. All sonic test data are presented in Table A.1(See Appendix).

It was discovered that the sonic test apparatus was malfunctioning shortly after the start of sonic velocity testing. Therefore, the sonic velocity test data taken before April 13, 1974 must be considered suspect. This includes sonic velocity test data taken through cycle 17, in Boreholes 1, 2, 3, and 4.

FIGURE 1. WET-DRY BORE HOLE NO. 1

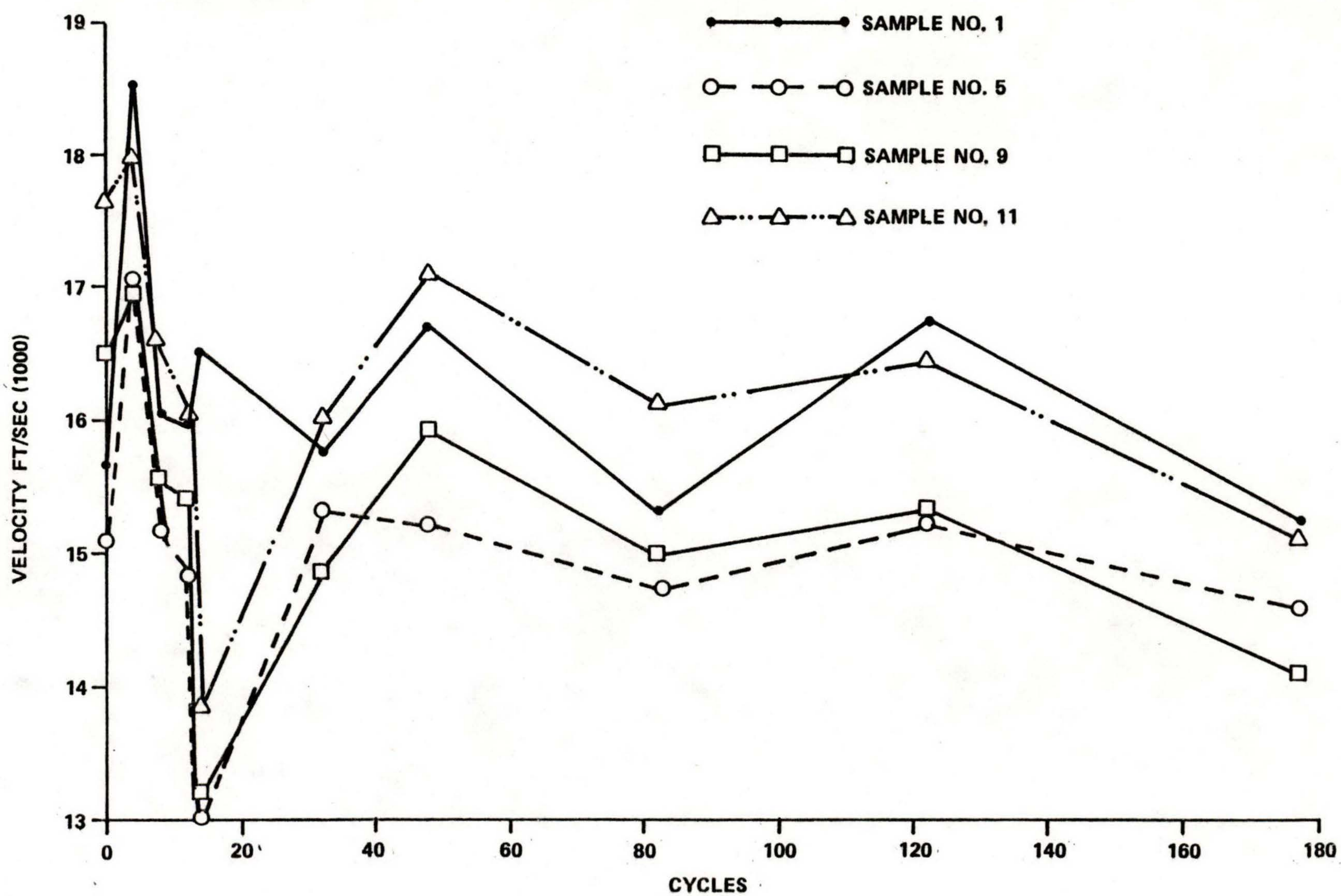


FIGURE 2. WET-DRY BORE HOLE NO. 2

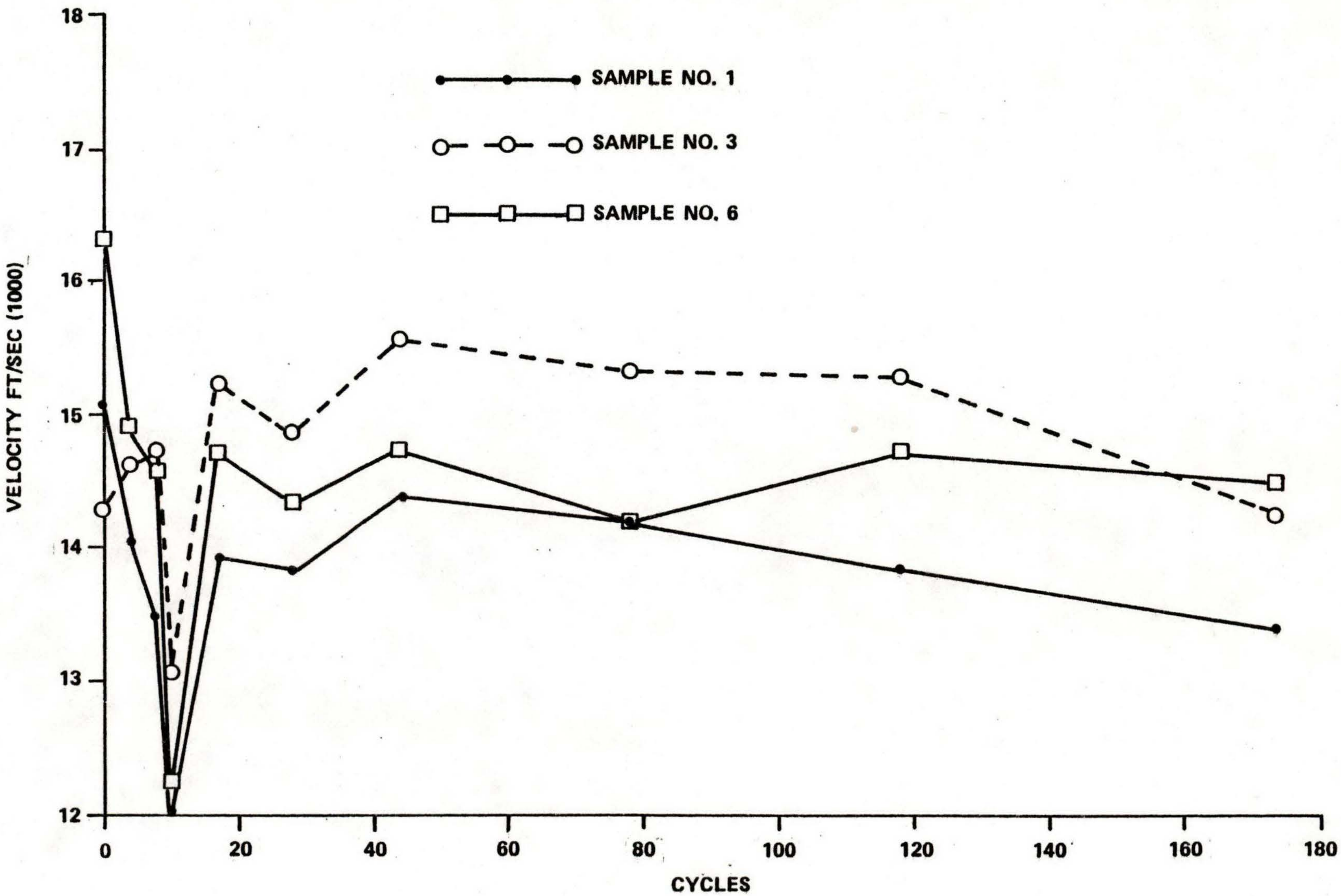


FIGURE 3. WET-DRY BORE HOLE NO. 3

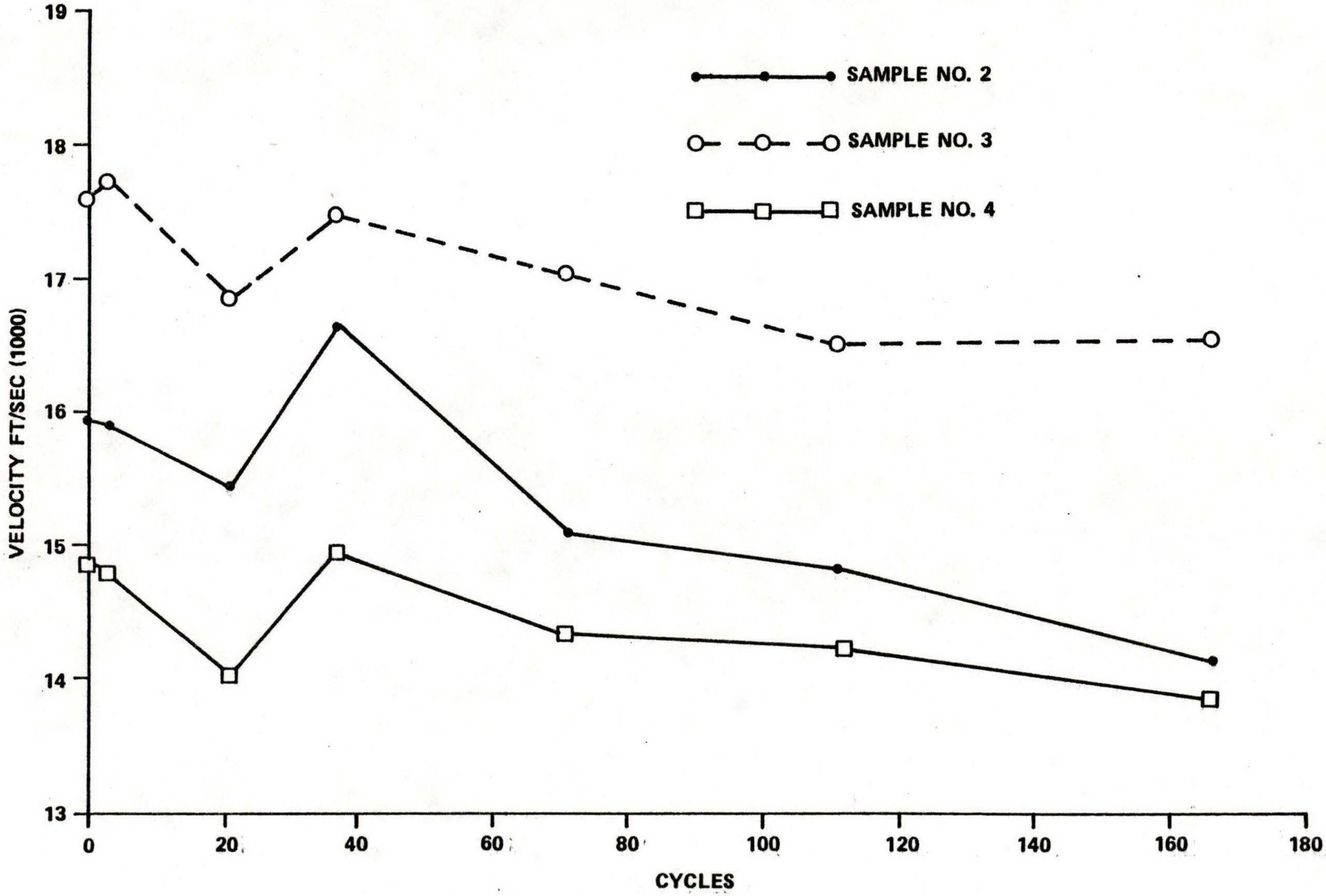


FIGURE 4. WET-DRY BORE HOLE NO. 4

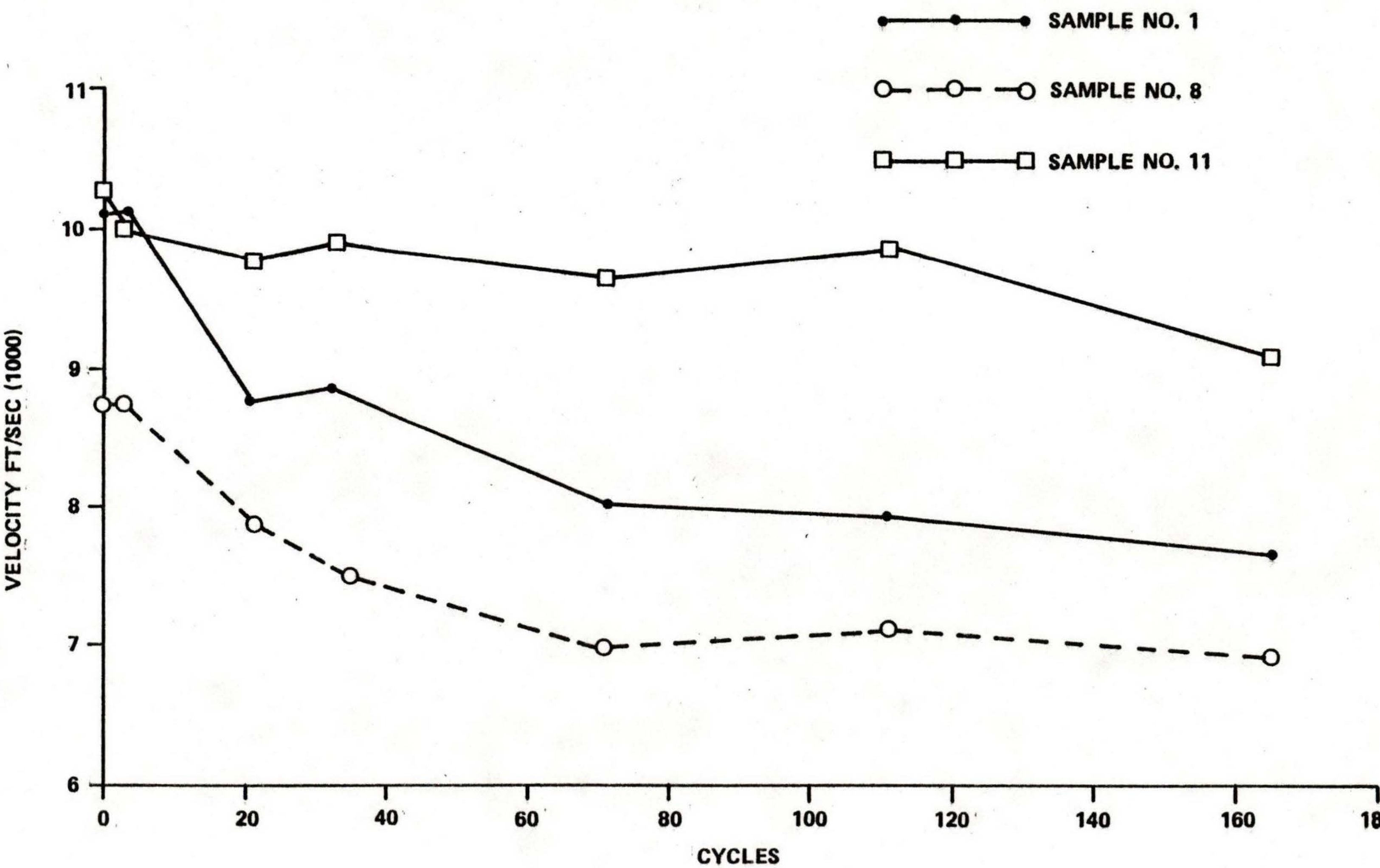


FIGURE 5. WET-DRY BORE HOLE NO. 5

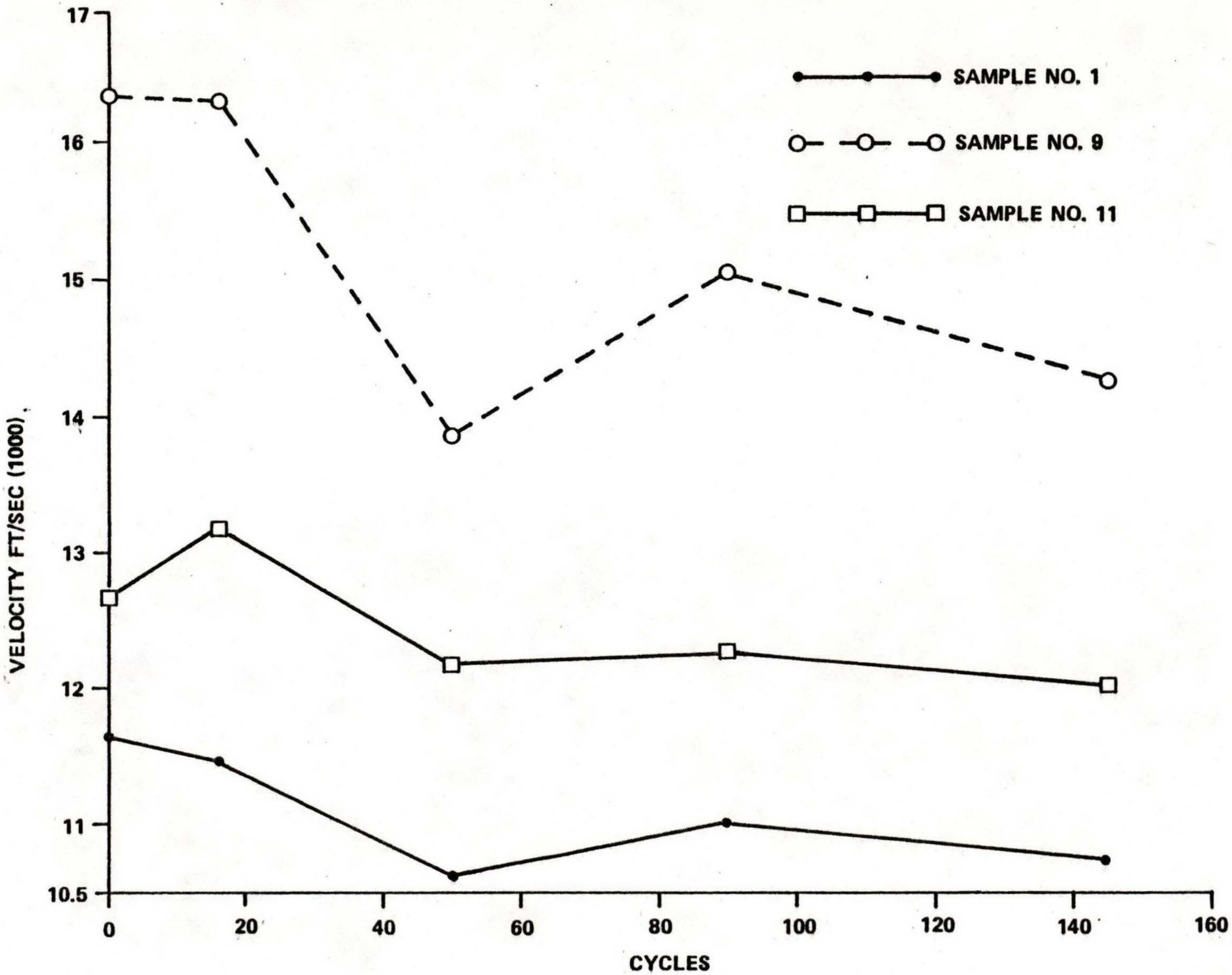


FIGURE 6. WET-DRY BORE HOLE NO. 7

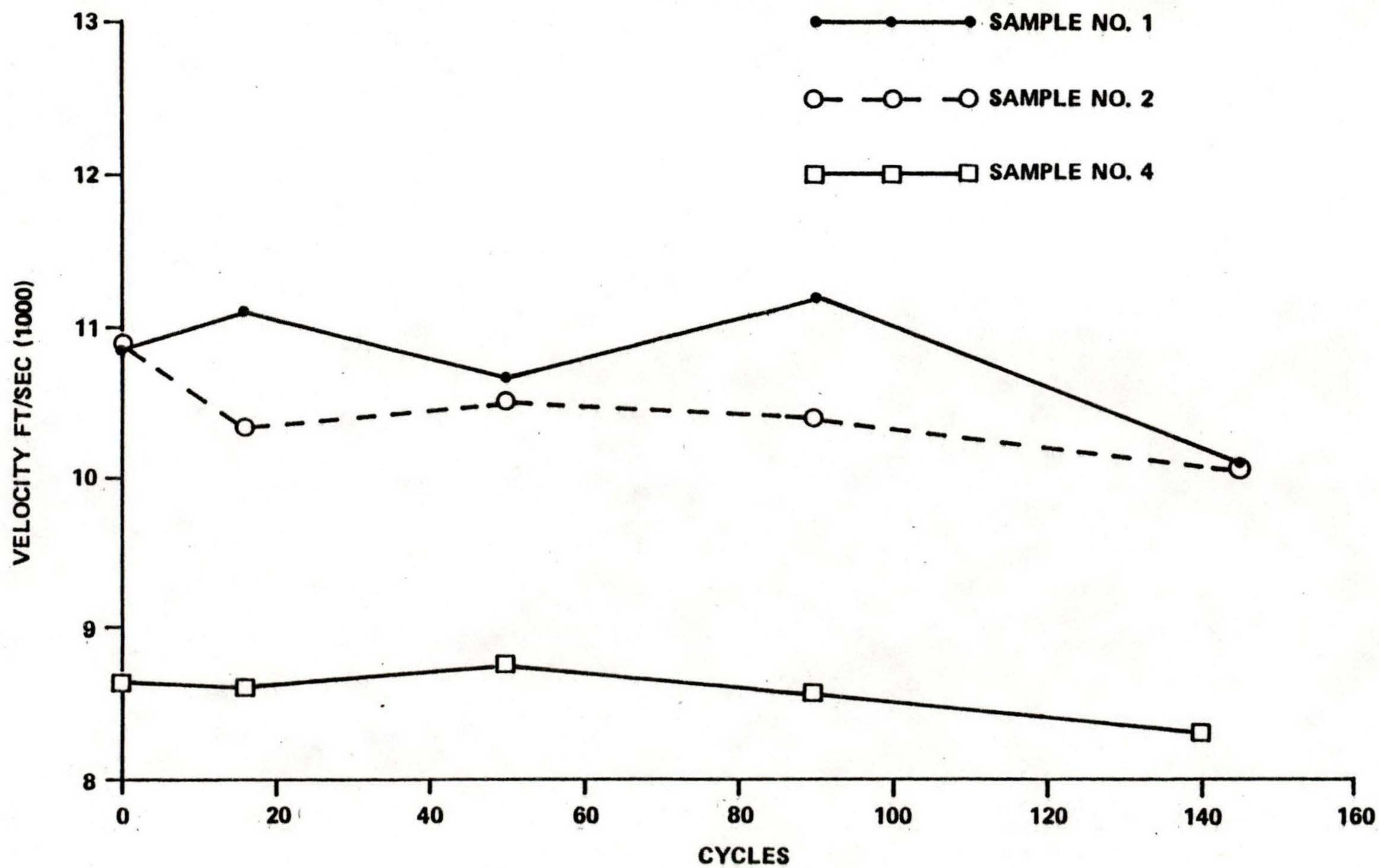


FIGURE 7. WET-DRY BORE HOLE NO. 10

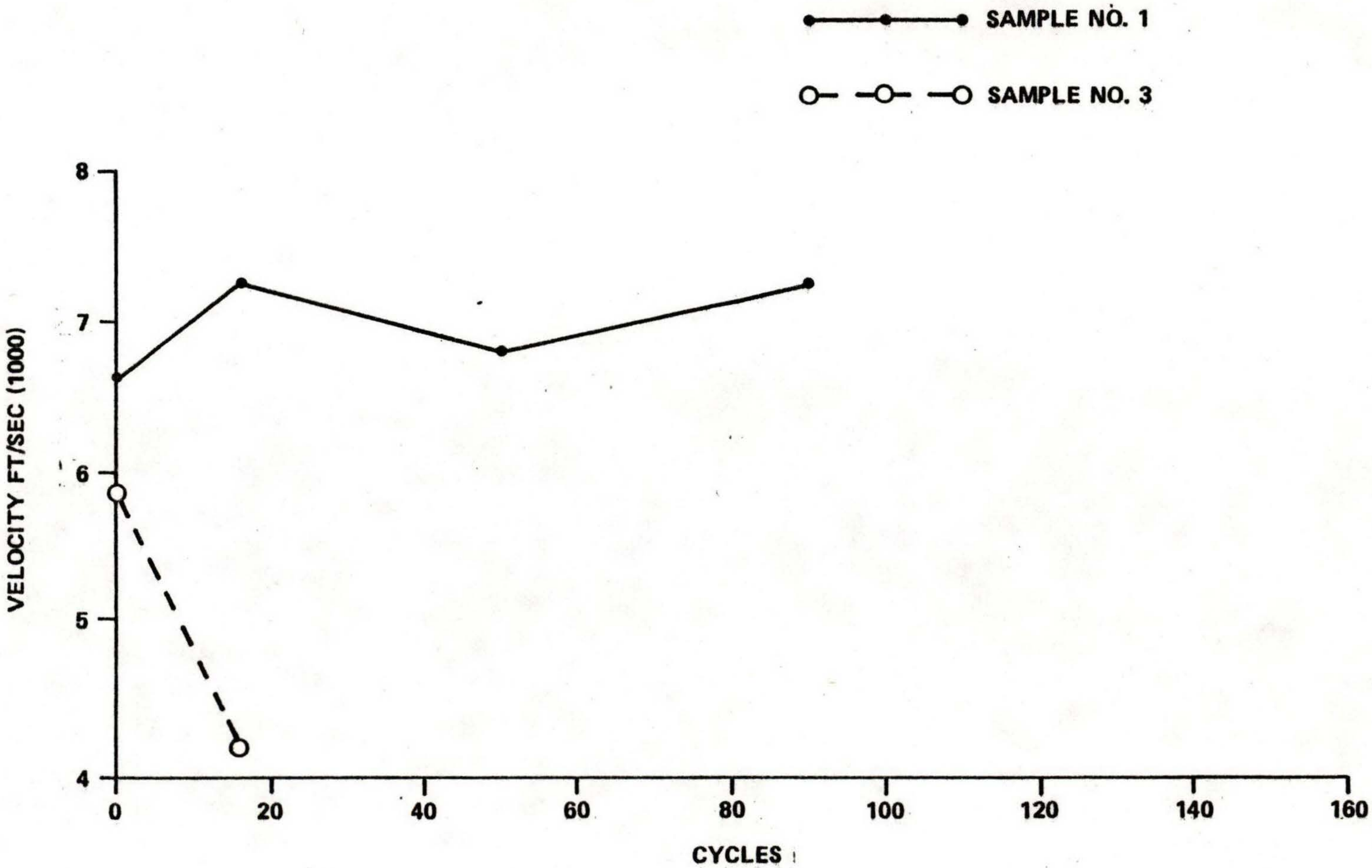


FIGURE 8. WET-DRY BORE HOLE 11

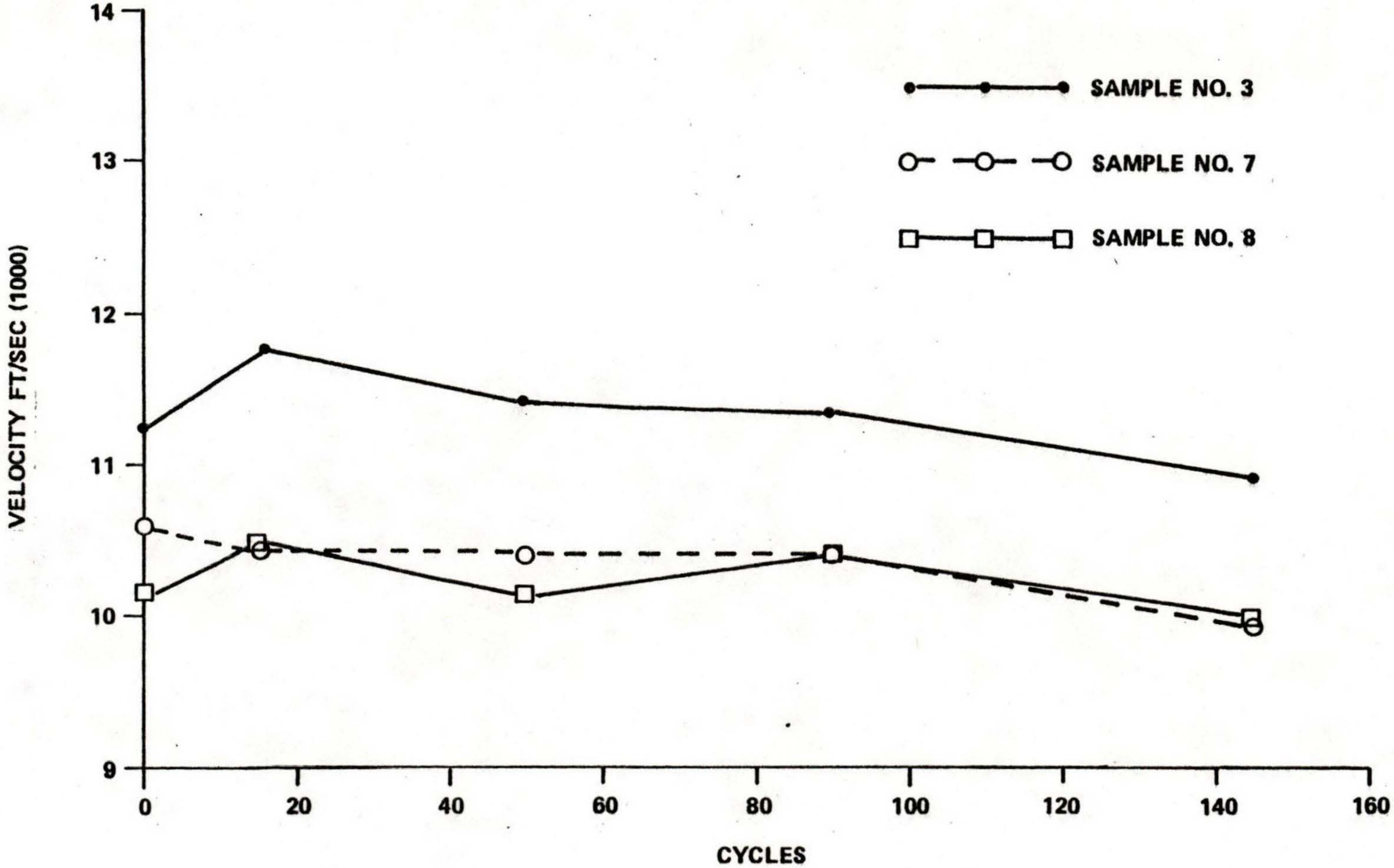


FIGURE 9. FREEZE-THAW BORE HOLE NO. 1

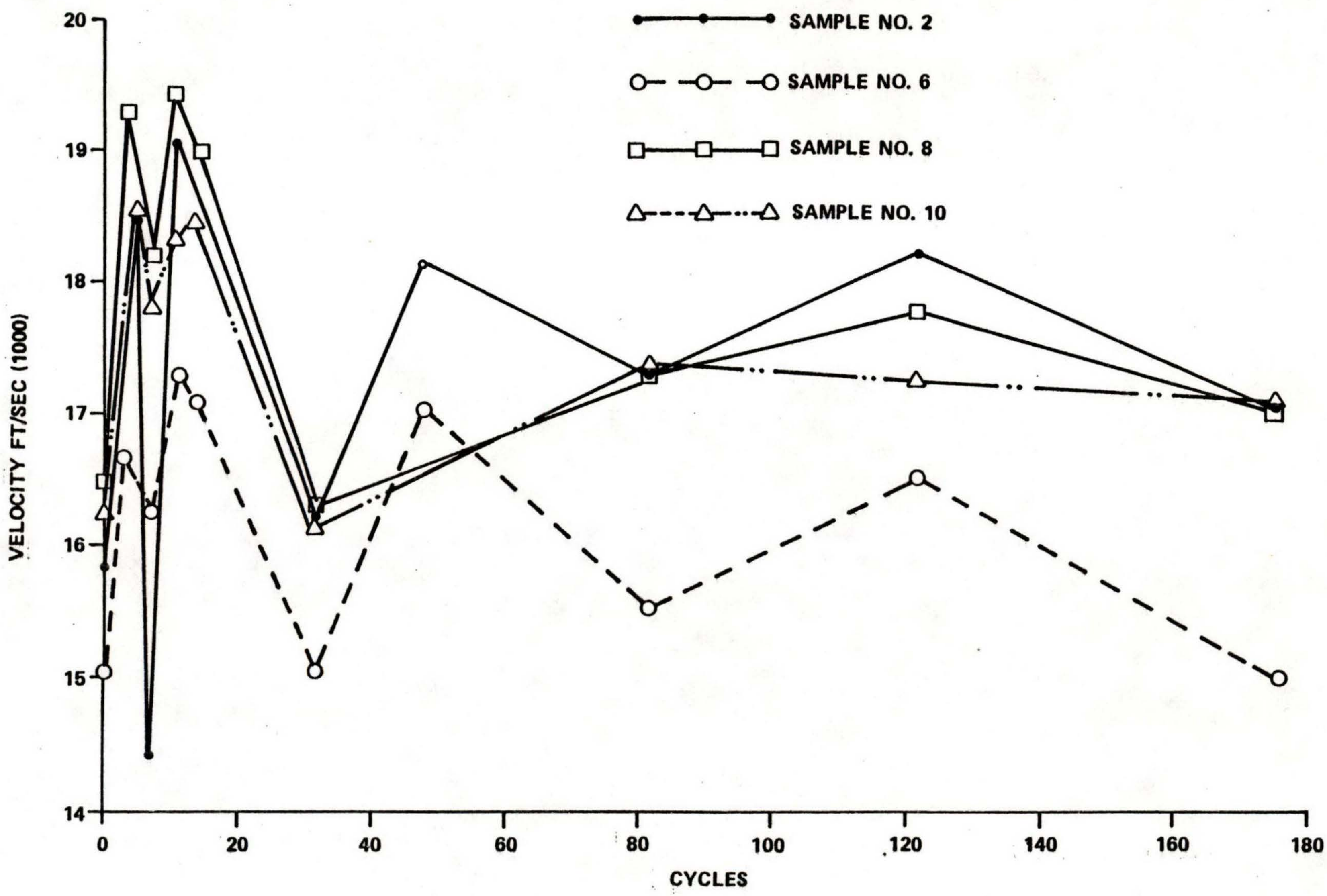


FIGURE 10. FREEZE-THAW BORE HOLE NO. 2

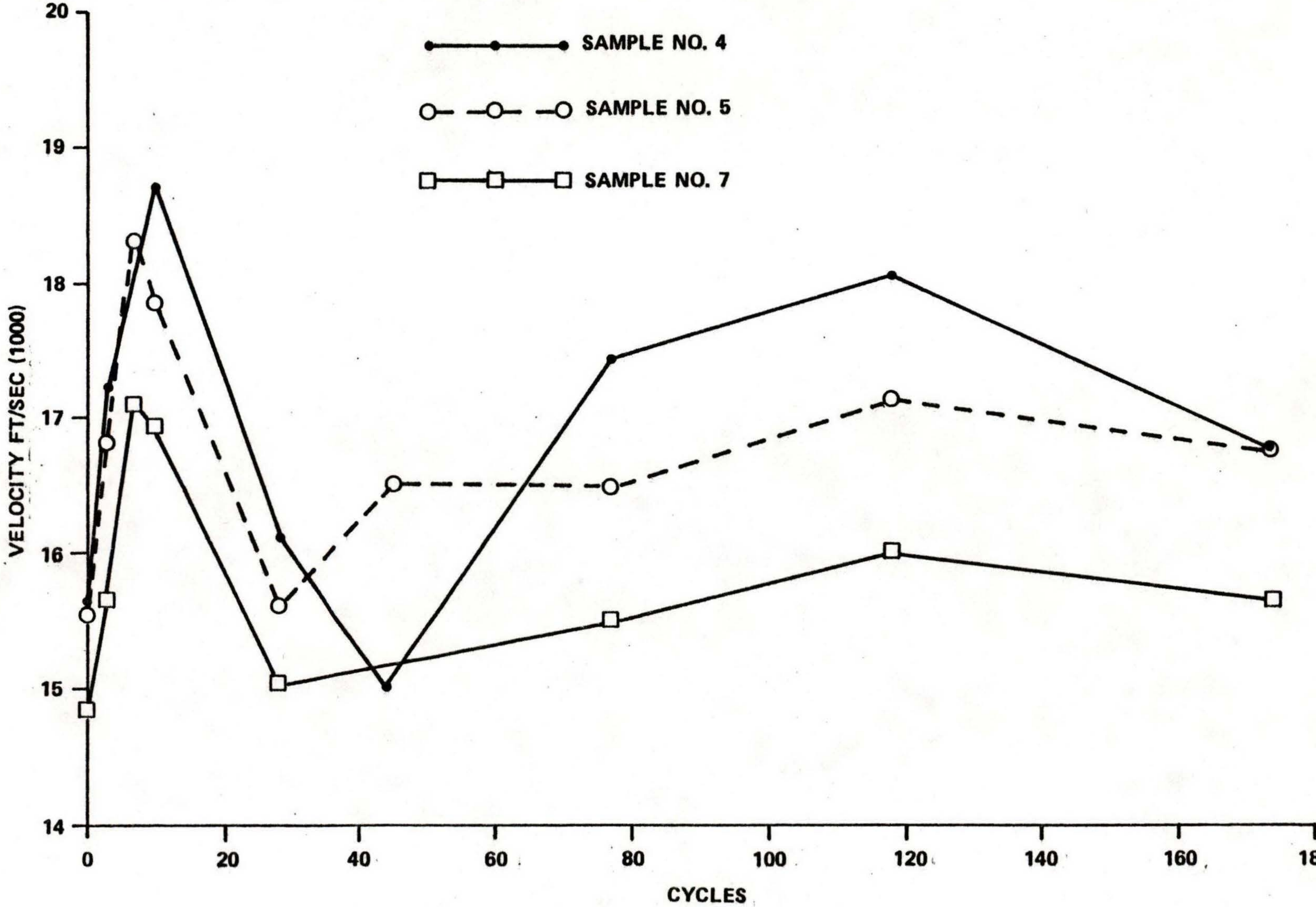


FIGURE 11. FREEZE-THAW BORE HOLE NO. 3

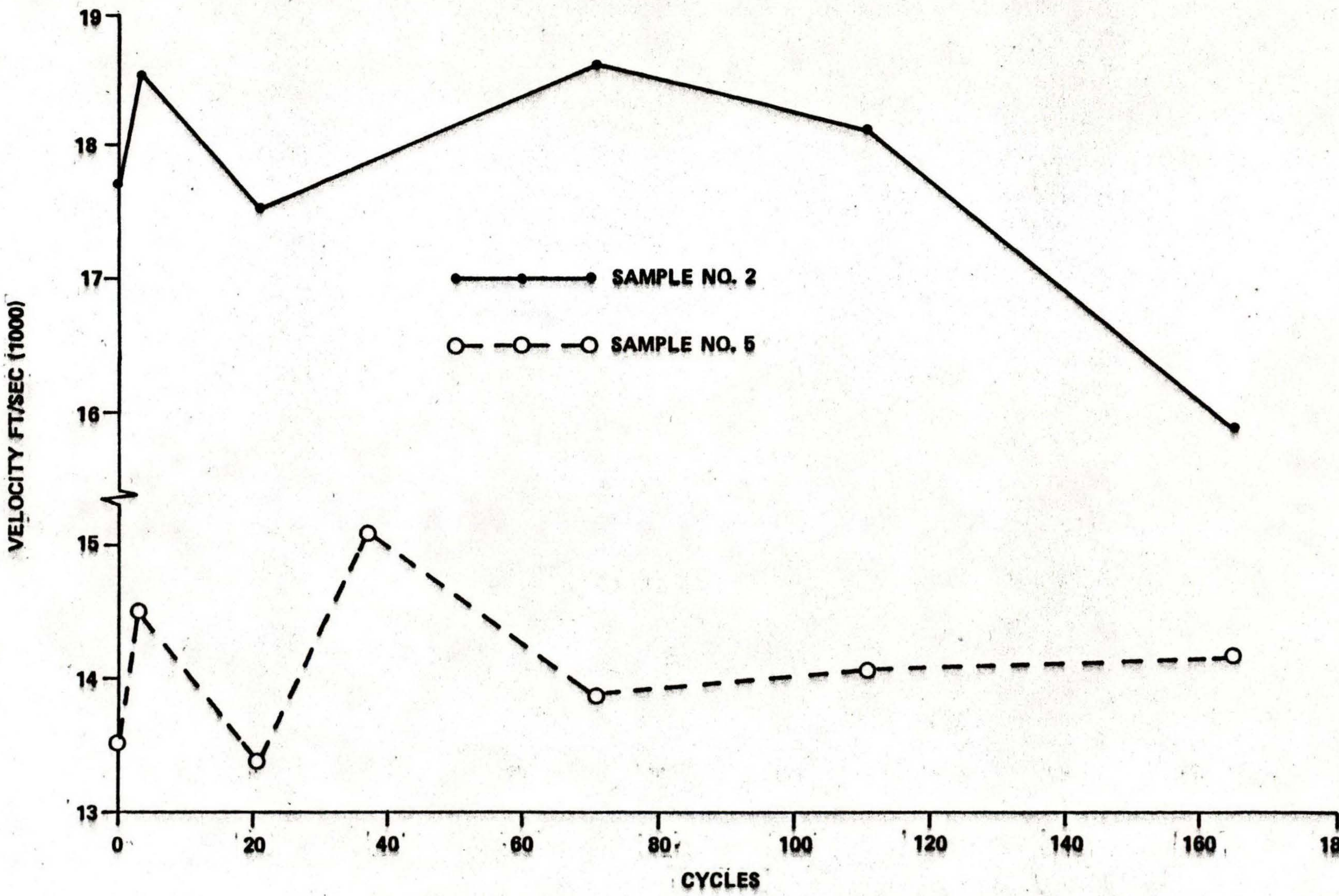


FIGURE 12. FREEZE-THAW BORE HOLE NO. 4

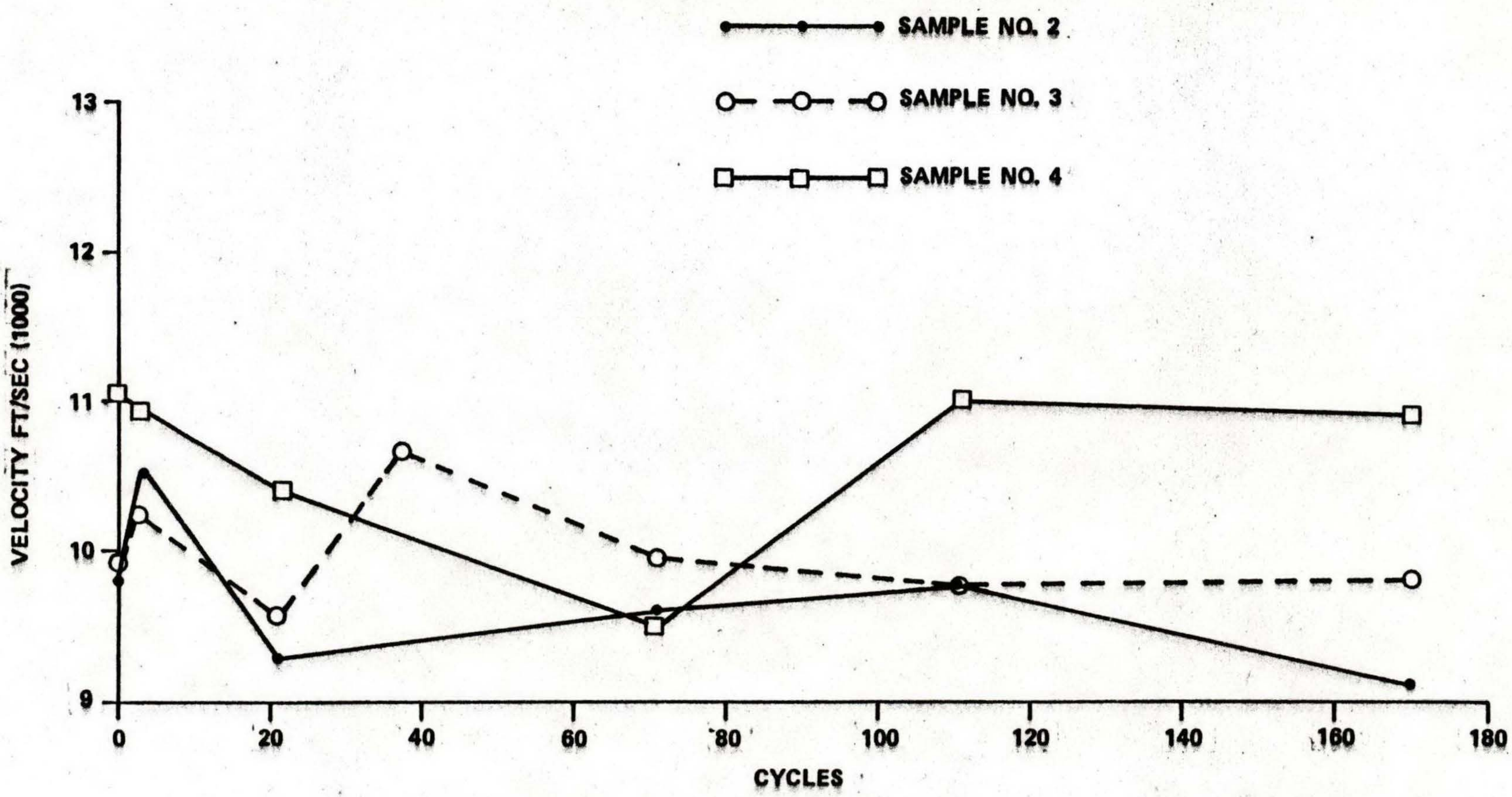


FIGURE 13. FREEZE-THAW BORE HOLE NO. 5

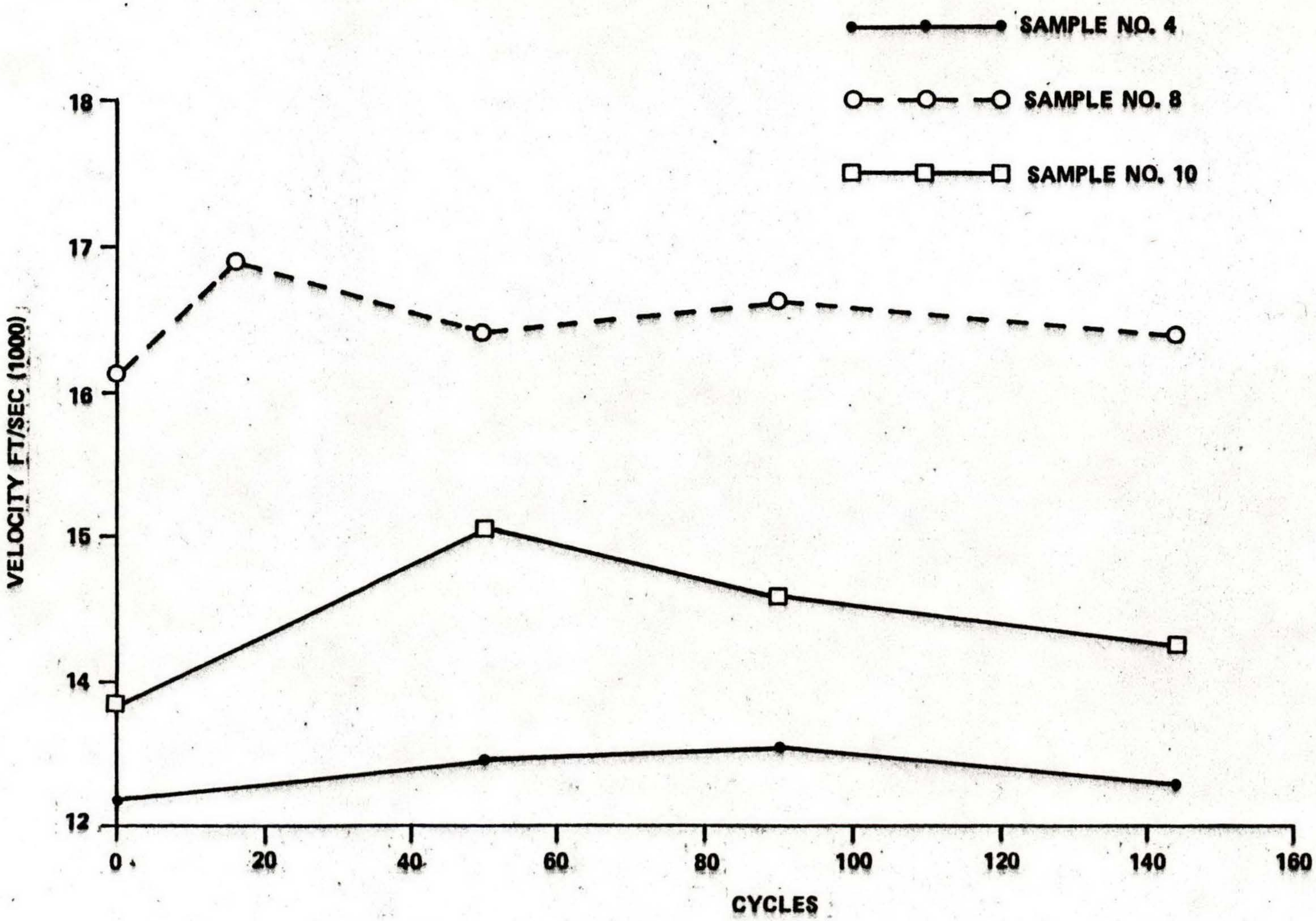


FIGURE 14. FREEZE-THAW BORE HOLE NO. 7

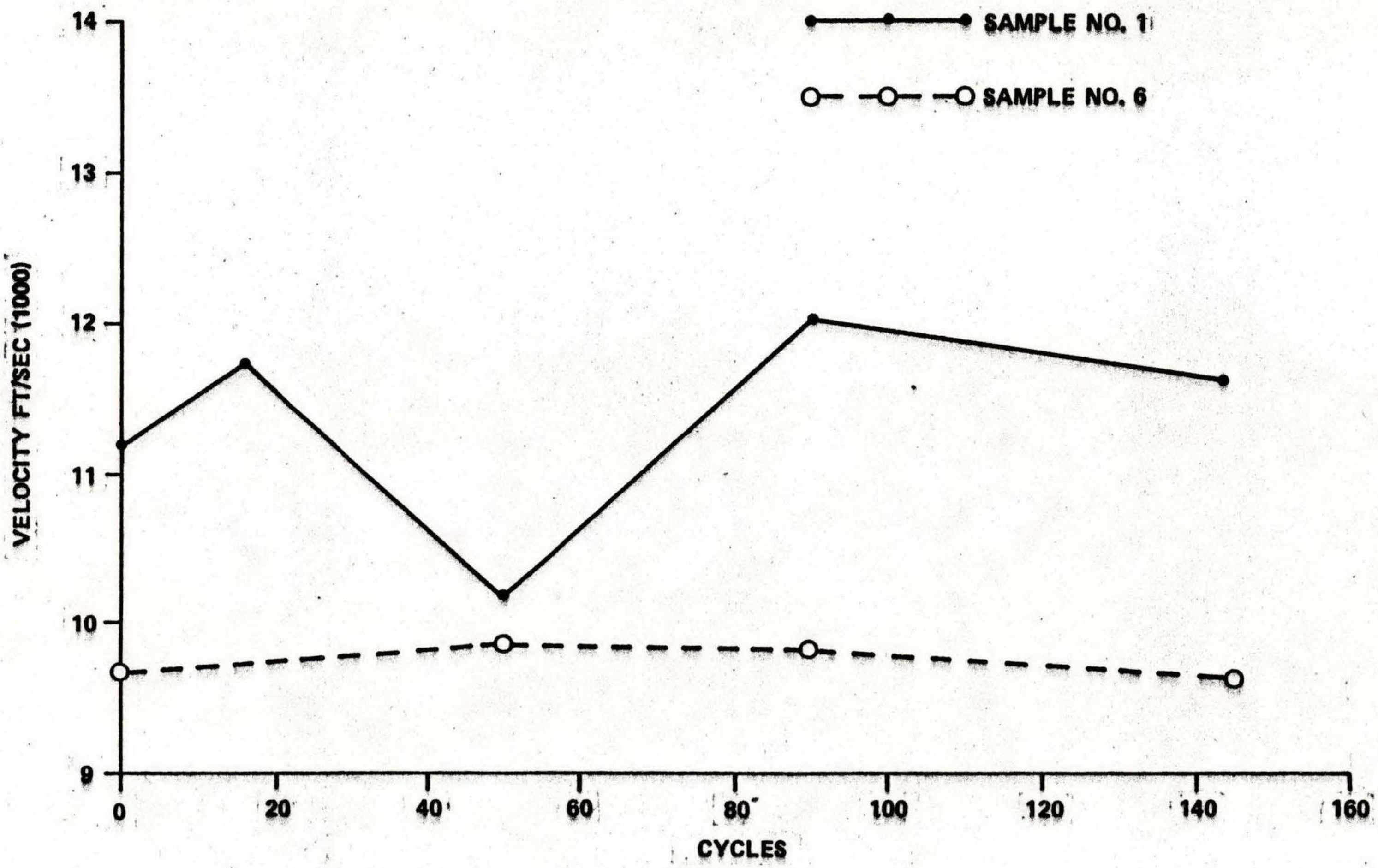
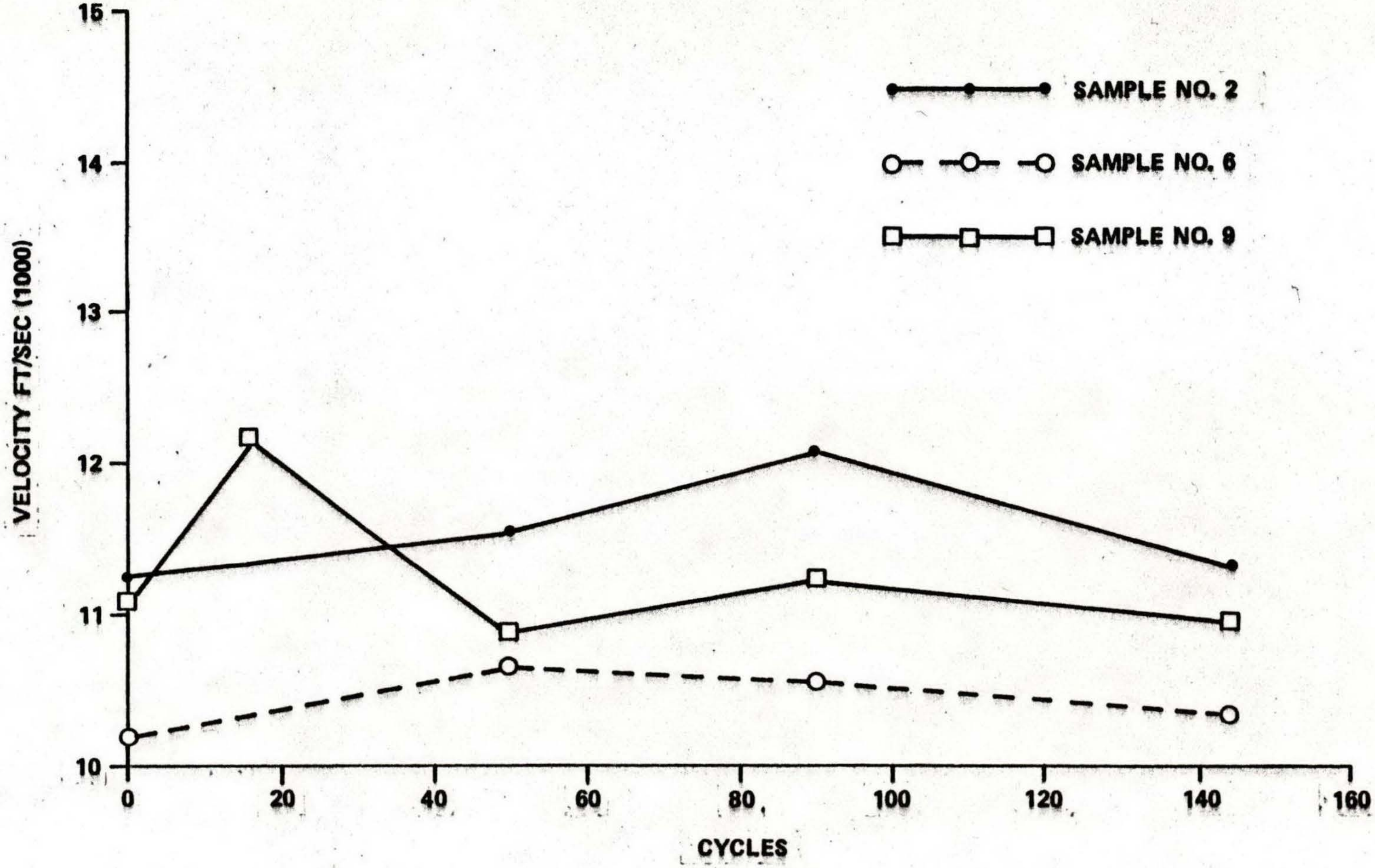


FIGURE 15. FREEZE-THAW BORE HOLE NO. 11



ANALYSIS OF DATA

Weathering Classification. Table 1.b shows the relationship between initial and final weathering classifications for the samples studied. Data show that the general trend was for the classification to remain the same or to increase. An increase in classification number is evidence that weathering has taken place due to environmental cycling. In one instance, it appears that the aforementioned trend reversed due to environmental cycling. This is most probably the result of an error in classification.

Data in Table 1.b show that the period of environmental testing was not sufficiently long to bring about substantial changes in the weathering stage of the samples. This is evidenced by the fact that the change in weathering classification, for each sample, was small or none existent.

It was not possible to subject samples from each boring to environmental cycling due to the inability to obtain intact rock samples of sufficient length from some of the borings. In addition, in some instances in which it was not possible to obtain a sample for environmental testing, it was possible to obtain a sample large enough for determination of unit weight and hardness. In such instances, no final test results are shown.

Hardness. All hardness test data are summarized in Table 2. These data show average hardness values, obtained for the borings tested, ranged between 11.8 and 78.0. Qualitatively, hardness reflects the weathering classification of rock, i.e. the higher the hardness number the least weathered the rock.

Tests on samples from a particular boring produced a range in hardness values. These variations in hardness test results reflect operator error and actual variations in hardness between samples from a particular boring.

In many instances, the final hardness test values exceed the initial values. This is in contrast to what was expected, i.e. the hardness of the samples should decrease with time as a result of weathering from environmental cycling. The reasons for the apparent anomaly most probably rest in a combination of factors. First, two different operators were used to establish the initial and final test values. Secondly, most of the initial hardness test values were determined on unlapped ends, while all the final hardness test values were determined on lapped ends. Experience has shown that lapping produces an increase in measured hardness.

Table 5 summarizes the results of statistical analyses performed on the initial and final hardness test data. These data represent the mean, standard deviation and probably error of a single measurement and show that the within operator variability permits a single operator to obtain consistent results. It is not possible to assess between operator variability since the effects of environmental cycling cannot be evaluted.

Based on the statistical data previously dicussed, the variation of hardness test results for a specific boring is acceptable.

It was initially thought that the reason the final hardness readings exceeded the initial values, which is anomalous, was that the final hardness values were determined on samples whose ends had been lapped while the initial hardness values were determined on unlapped ends. Correspondingly, a comparison was made been hardness values taken only on the sides of the specimens. Using hardness data only from the sides of samples produced no change in the relative magnitude of the initial and final hardness values, i.e. the final values were still larger. Since it has been shown that a given operator can produce consistent results, this anomalous condition must be the result of between operator variability which was sufficient to mask the de-

Table 5. Summary of Statistical Data on Operator Variability -- Hardness Test

Boring No.	Specimen No.	Mean		Standard Deviation		Probable Erro	
		X_1	X_2	σ_1	σ_2	ϵ_1	ϵ_2
1	1		73.2		13.6		9.2
	2		79.7		15.2		10.3
	3	60.8		6.2		4.2	
	5		69.7		12.2		8.3
	6		75.0		16.5		11.1
	7		76.1		15.8		10.6
	8		76.4		16.9		11.4
	9	82.0	80.7	12.4	14.0	8.4	9.5
	10	83.0	81.7	13.6	17.8	9.2	12.0
	11		78.9		14.3		9.6
	12	77.8		15.3		10.3	
2	1	73.6	68.6	16.6	12.7	11.2	8.6
	2	72.3	76.0	16.5	16.6	11.1	11.2
	3	79.1	80.5	15.2	13.5	10.2	9.1
	4	82.7	84.2	14.6	15.1	9.9	10.2
	5	79.6	81.2	15.8	19.8	10.6	13.3
	6	77.6	77.1	17.0	14.8	11.4	10.0
	7	81.4	81.4	13.8	13.7	9.3	9.2
3	1		74.4		13.7		9.3
	2	66.7	68.7	9.7	12.6	6.5	8.5
	3	69.8	70.6	12.1	14.2	8.1	9.6
	4	67.0	69.0	10.3	12.8	7.0	8.6
	5	67.1	68.4	11.9	14.2	8.0	9.6
4	1	31.7	36.4	11.0	10.5	7.4	7.1
	2	33.3	35.9	7.9	6.7	5.4	4.5
	3	37.5	40.8	8.5	5.8	5.7	3.9
	5	29.9	41.4	7.7	8.1	5.2	5.4
	8	26.8	33.0	6.5	7.8	4.4	5.3
	10	30.6	48.5	11.4	12.4	7.7	8.3
	11	36.9	39.4	14.0	8.8	9.4	5.9

Table 5 (cont)

Boring No.	Specimen No.	Mean X_1	Mean X_2	Standard Deviation σ_1	Standard Deviation σ_2	Probable Error ϵ_1	Probable Error ϵ_2
5	1	54.6	60.3				
	4	55.4	64.0				
	7	59.8	72.3				
	8	64.1	69.0				
	9		71.9				
	10	56.9	65.0				
	11	55.9					
7	1		54.4		11.2		7.6
	1		65.6		15.6		10.5
	2	51.1	62.7	7.2	13.1	4.9	8.9
	4	31.4	32.7	6.4	8.2	4.3	5.5
	4	45.1	44.7	6.6	7.2	4.5	4.9
	6	42.4	48.3	5.9	9.7	4.0	6.5
8	1	31.3	34.1	6.7	9.7	4.6	6.5
	2	18.0	24.4	5.8	7.4	3.9	5.0
	3	21.2		4.7		3.2	
9	1	13.1		5.8		3.9	
	2	17.4		8.9		6.0	
	3	32.5		22.7		15.3	
10	1	13.7	13.1	5.8	4.9	3.9	3.3
	2	13.1	15.4	4.9	4.2	3.3	2.8
	3	10.6		4.1		2.8	
	4	8.8		3.2		2.1	
	5	12.7		4.6		3.1	
11	1	68.1		7.3		4.9	
	2	66.1		5.9		4.0	
	3	63.2		6.2		4.2	
	6	47.8	57.1	6.5	9.0	4.4	6.1
	7	47.0	49.3	8.8	11.3	5.9	7.6
	8	53.0		6.8		4.6	
	9	51.9	59.7	7.4	8.9	5.0	6.0

crease in hardness caused by environmental cycling.

An evaluation was made of the effect of lapping on the average hardness values and the results are presented in Figure 16. The data presented in the aforementioned figure is based on the average of 40 hardness values taken on lapped ends and an equal number taken on the unlapped sides. Figure 16 shows that standard deviation tends to increase with average hardness. This indicates that more readings must be taken to obtain a given level of precision for high hardness values as compared to low hardness values. However, the same precision can be obtained with a sample size of 40 when the average hardness value is 20.

Two other facts are apparent from Figure 16. First, the data collected on the core sides tend to be less variable than data collected on core ends, as indicated by the narrower confidence bands around the regression line for the core-side data. Second, hardness values tend to average higher on the lapped core ends as compared to the core sides. This latter observation is better illustrated in Figure 17 where average hardness values for lapped core ends are plotted against similar values for core sides. The data show that values for lapped core ends exceed values for core sides when hardness values are high, but not when they are low. It is to be expected that, when cores are very hard, smoothed surfaces experience mose elastic rebound as compared to rougher surfaces where the impact may not occur normal to the surface. However, as the rocks become softer, the differences become smaller and finally disappear altogether. In addition, the lapping process causes "work hardening" of the core ends which increases the average hardness above that for unlapped surfaces.

Summarizing the above we find that hardness readings collected on core sides are less variable and tend to average lower than similar data collected on core ends. Statistically speaking, this means it is more desirable to take hardness readings

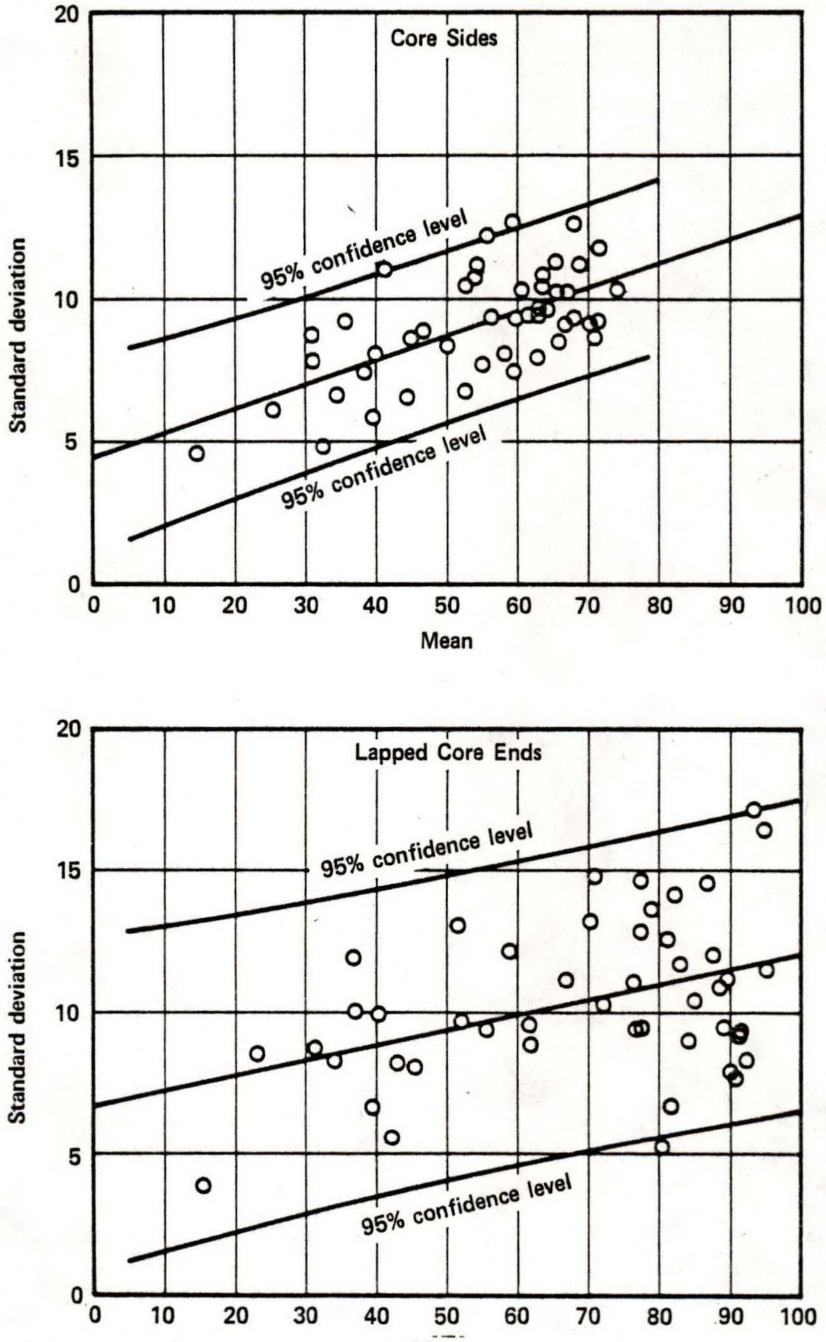
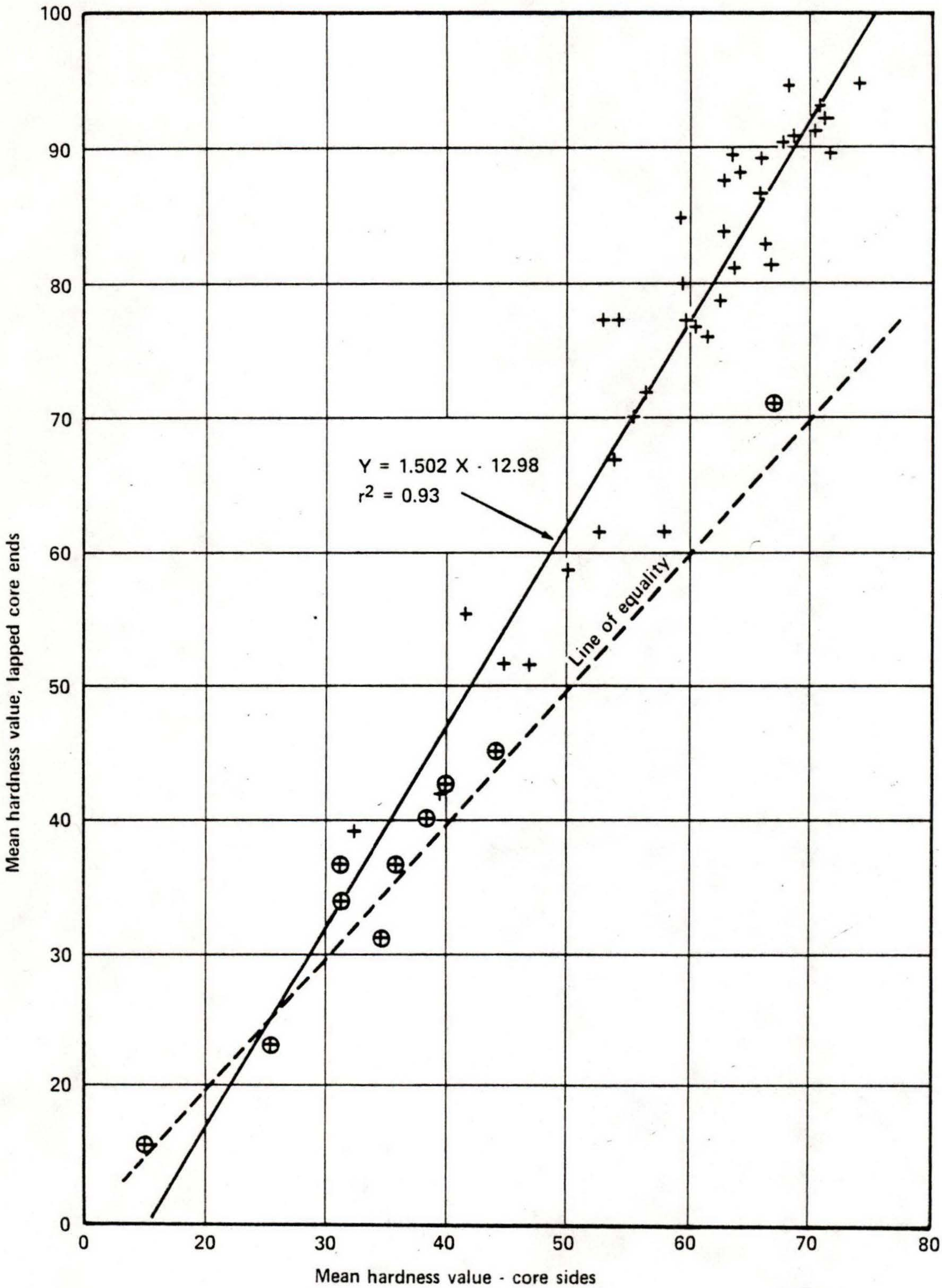


Fig. 16 Standard deviation vs. mean hardness values



Note: All means are significantly different at the 0.05 level unless circled

Fig. 17 Comparison of average readings on lapped core ends and core sides. Each point represents a mean of 40 readings

on core sides as compared to lapped core ends because fewer samples are needed to attain a given level of precision. Thus, core sides are recommended for obtaining average hardness values even if there were no additonal cost for lapping cores (as, for example, when lapping is required anyway for mineralogical examinations).

Unit Weight. Unit weight determinations were made on each specimen both before and after environmental cycling. The results (see Table 2) generally indicate a decrease in unit weight with a decrease in hardness. Furthermore, the data generally indicate decreases in unit weight, as a result of environmental testing, were small which is consistent with the other data which indicated a small effect of environmental testing on the weathering state of the samples tested.

Unconfined Compressive Strength. Unconfined compressive strength tests (see Table 2) were conducted on all specimens which survived the environmental cycling plus control specimens. In general, the average unconfined compressive strength decreased with average hardness. However, there were substantial variations in unconfined compressive strength within samples taken from a particular boring. Such variations most likely represent the results of natural differences between samples, e.g. the presence or absence of cracks, seams, quartz intrusions, etc.

Sonic Velocity. Sonic velocity measurements were made at irregular intervals after the start of environmental cycling. The last series of sonic velocity measurements were made immediately following the termination of environmental cycling, and prior to the conduct of the unconfined compression tests. All data from these are presented in Figures 1 to 15, inclusive and in Table A.1., in the appendix. In addition, the sonic velocity measurements are summarized in Table ~~5~~ 6.

All sonic velocity measurements were made by the same person. In addition, as previously cited, operator error was relatively small.

Table 6. Summary of Sonic Velocity Test Results

Boring No.	Sample No.	Test Type	Initial Hardness	Number of Cycles	Sonic Velocity, fps Initial	Sonic Velocity, fps Final
1	1	W-D	71.0	177	15,689	15,245
	5	W-D	70.7	177	17,073	14,582
	9	W-D	82.0	177	16,499	14,092
	11	W-D	83.2	177	17,627	15,111
	2	F-T	72.5	176	15,822	17,058
	6	F-T	71.6	176	15,037	14,975
	8	F-T	74.0	176	16,465	16,998
	10	F-T	83.2	176	16,223	17,089
2	1	W-D	73.5	173	15,075	13,389
	3	W-D	79.1	173	14,262	14,255
	6	W-D	77.3	173	16,324	14,477
	4	F-T	82.7	174	15,612	16,747
	5	F-T	79.7	174	15,535	16,769
	7	F-T	81.4	174	14,825	15,644
3	2	W-D	66.7	166	15,936	14,131
	3	W-D	72.6	166	17,592	15,546
	4	W-D	66.9	166	14,849	13,821
	1	F-T	67.2	165	18,198	16,385
	5	F-T	67.0	165	13,518	14,124
4	1	W-D	31.6	165	10,112	7,676
	8	W-D	26.7	165	8,730	6,921

Boring No.	Sample No.	Test Type	Initial Hardness	Number of Cycles	Sonic Velocity Fps. Initial	Final
4	11	W-D	36.9	165	10,260	9,103
	2	F-T	33.3	165	9,775	9,137
	3	F-T	37.8	165	9,903	9,830
	10	F-T	38.2	165	11,059	10,939
5	1	W-D	54.6	145	11,645	10,722
	9	W-D	65.8	145	16,358	14,283
	11	W-D	55.9	145	12,675	12,010
	4	F-T	55.4	144	12,182	12,292
	8	F-T	64.1	144	15,101	15,397
	10	F-T	56.9	144	12,873	13,223
7	1	W-D	51.5	145	10,867	10,087
	2	W-D	50.4	145	10,900	10,052
	4	W-D	31.4	145	8,636	8,299
	1	F-T	59.6	144	11,198	11,612
	6	F-T	42.3	144	9,655	9,632
11	3	W-D	63.2	145	11,248	10,926
	7	W-D	47.0	145	10,585	9,926
	8	W-D	53.9	145	10,137	10,009
	2	F-T	66.1	144	11,242	11,333
	6	F-T	47.8	144	10,177	10,332
	9	F-T	51.9	144	11,069	10,942

Data generally show decreases in sonic velocity with environmental cycling. This trend is most readily portrayed in Table 6. Exception to this trend are also apparent in Table 6. It is felt that these exceptions are the result of the masking of the true trends by operator and equipment variability, i.e. the variation in sonic velocity measurements, though small, in some cases were sufficient to obscure the trend in the data.

It must also be noted that sonic velocity data taken prior to April 13, 1974 is not valid due to malfunctioning of the equipment. This invalidates the first five data points in Borings 1 and 2 and the first 2 in Borings 3 and 4.

There was also a general trend toward a decrease in sonic velocity with a decrease in hardness, for both conditions of environmental testing.

A special series of tests were conducted to evaluate operator variability of sonic velocity test data. Five specimens were tested by the same operator, at approximately one week intervals, and the data subjected to statistical analyses. These tests were performed by the same person who conducted all the sonic velocity tests reported herein.

The results of these tests are summarized in Table 6. These data show that operator variability is relatively small. Nevertheless, this relatively small amount of variability may have been sufficient to mask deterioration in the rock specimens caused by environmental cycling.

Hardness as a Predictor of Rock Properties

Weathering. Sampling sites were chosen on the basis of weathering classification in accordance with the system proposed by Clayton and Arnold 2 for intrusive rocks found in the Idaho Batholith.

One would expect a hard, unweathered rock to exhibit more elastic rebound, as measured by the hardness test, than a similar rock in a highly weathered state.

Table 7. Summary of Statistical Data on Operator Variability -- Sonic Velocity Tests

Boring No.	Specimen No.	Nominal Stress Level, psi	$\bar{X}$, psi	σ	ϵ
1	10	0	14,626	220	149
		110	14,645	118	79
		330	15,148	208	140
		360	15,950	104	70
3	3	0	14,224	208	140
		110	14,372	628	423
		330	15,920	393	265
		660	17,089	211	143
4	2	0	-	-	-
		110	6,596	245	165
		330	8,574	285	192
		660	9,682	114	77
5	7	0	12,437	370	249
		110	12,461	102	69
		330	13,395	192	129
		660	14,493	138	93
11	9	0	6,577	285	192
		110	8,091	188	127
		330	10,000	69	46
		660	11,047	211	142

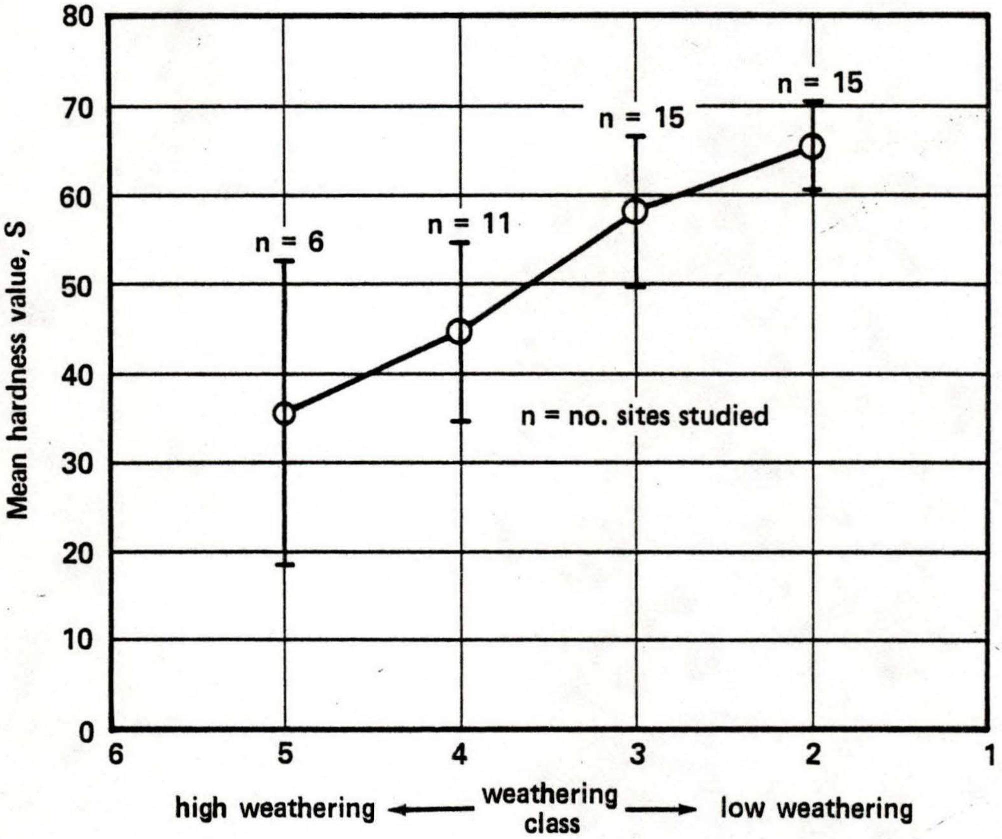


Fig. 18 Mean and standard deviation of hardness values vs. rock weathering class

To investigate this, means and standard deviations of hardness values from 47 study sites were plotted against the appropriate rock weathering class for each site (Figure 18). The data exhibit considerable scatter. However, it is apparent that hardness values decrease as rock weathering increases.

In view of the relationship found between hardness values and rock weathering, it was decided to investigate the direct relationship between hardness and selected rock properties in hopes that easily obtained hardness measurements would provide an index of various rock properties. Two data sets were used in each case, one from each of the two cooperative studies between Howard University and the F.S.L.B.[3]. Unfortunately, secant modulus data were only available from the first cooperative study.

Similar laboratory procedures were used to obtain all data in both studies; however, the hardness values were summarized differently. All 80 hardness readings (40 readings on core sides and 20 readings on each lapped, core end) were used to determine the average hardness value for a given rock core in the first study. In the analysis of the second study, results the average hardness value for a core was calculated using only the 40 readings taken on the core sides.

Unit Weight. The relationships between core unit weights and mean hardness values for the two data sets are shown in Figure 19. Regression analyses show that hardness provides a good index of rock core unit weight as indicated by relatively high coefficients of determination (r^2) in both cases. The relationships are curvilinear as might be expected because the weight of a particular rock sample tends toward a constant depending upon the specific gravity of its constituent minerals.

As previously cited, the hardness values for the first data set were calculated from both core sides and lapped, core-end readings while the hardness values for the second study were calculated only from core-side data. As shown in Figure 3, hard-

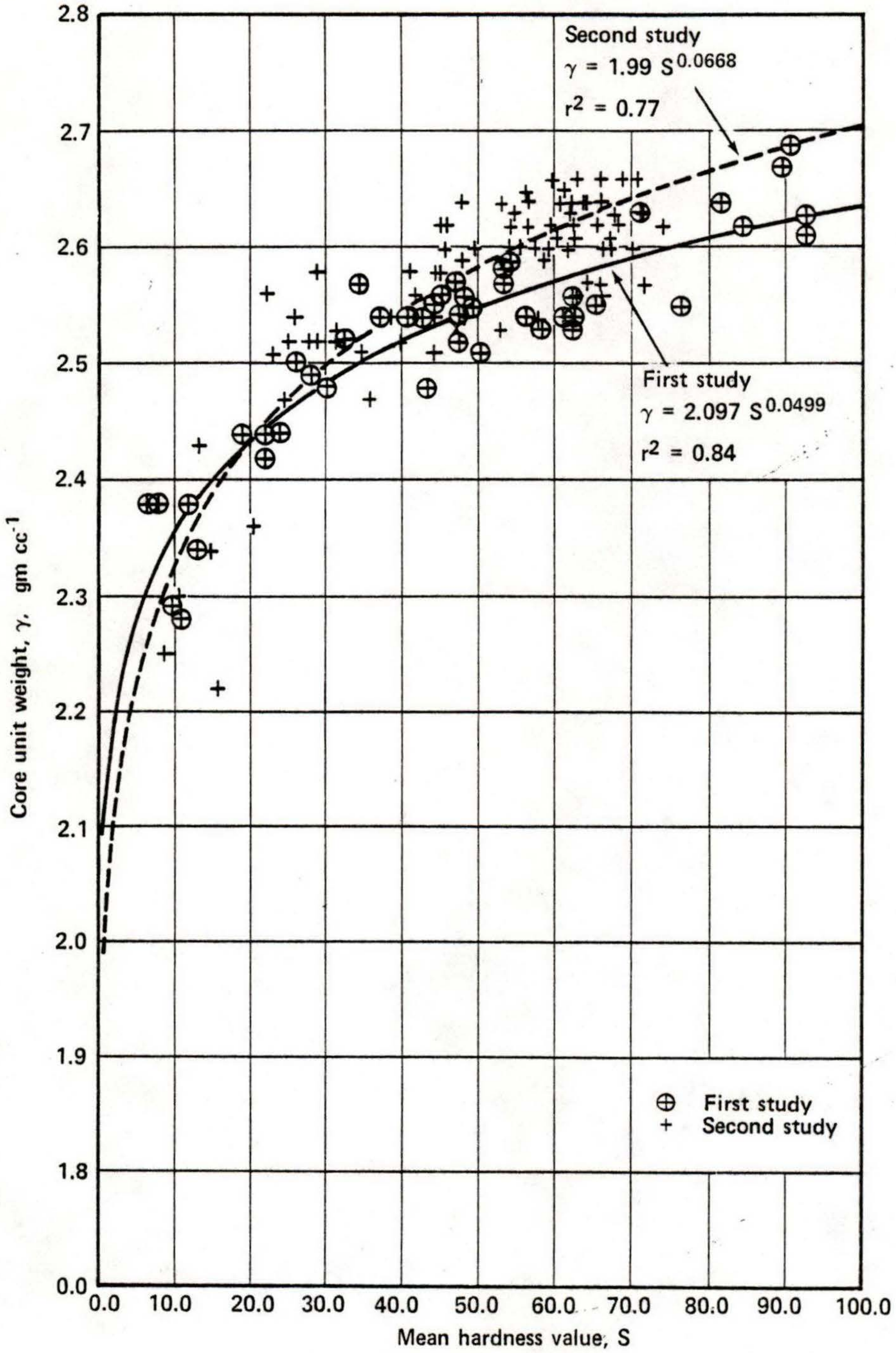


Fig. 19 Core unit weight vs. mean hardness value for 2 data sets

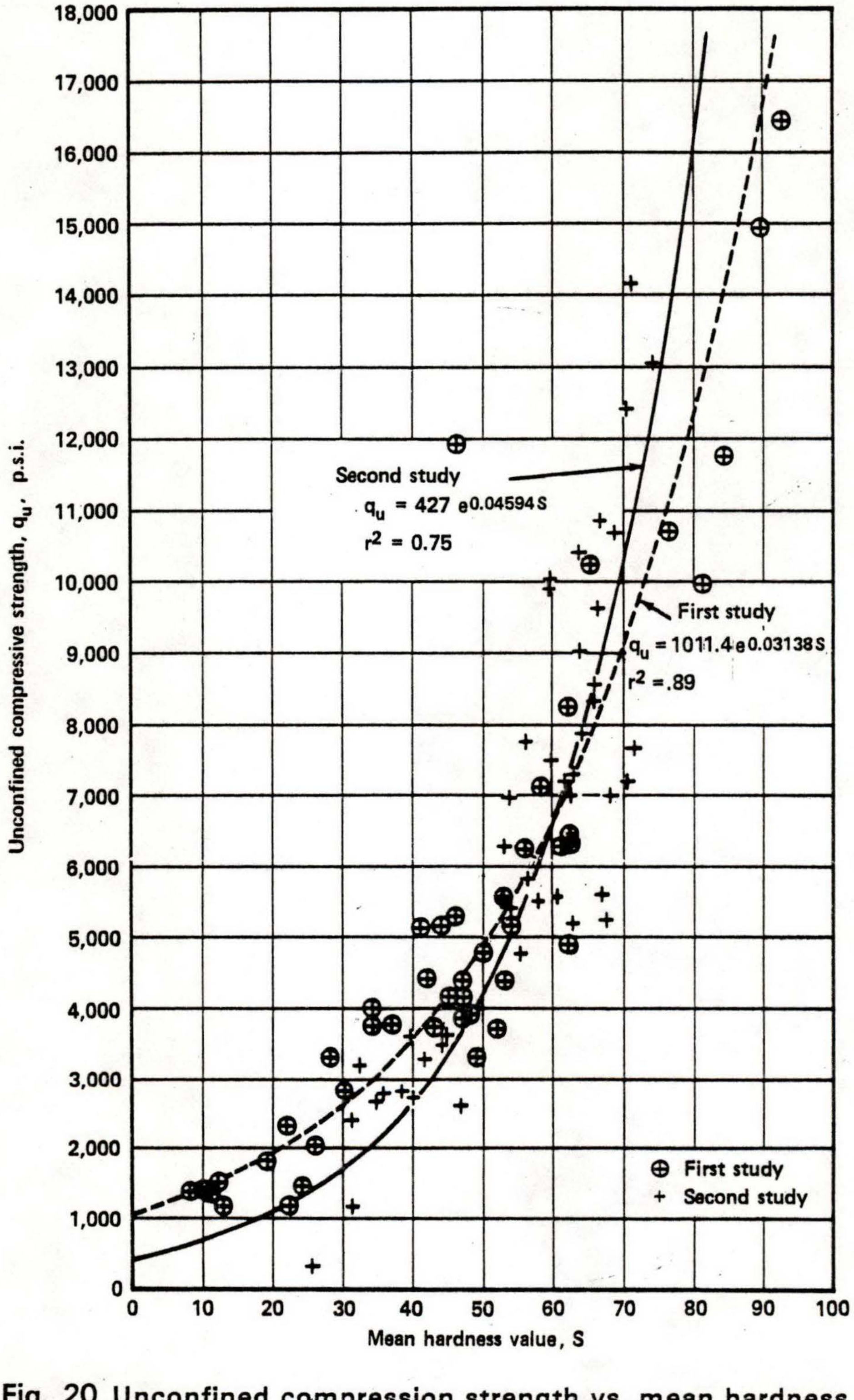


Fig. 20 Unconfined compression strength vs. mean hardness value for 2 data sets

ness values for lapped core ends exceed values for core sides when hardness values are high, but not when they are low. This effect is shown by the two fitted curves on Figure 19. When hardness values are high, the curve for the first study falls to the right of the curve for the second study for a given volume weight. However, the differences decrease as hardness values get smaller. For very low hardness values, the situation reverses and the curve representing the first study data falls to the left of the curve for the new study.

Unconfined Compressive Strength. The relationships between unconfined compressive strength and mean hardness values are shown on Figure 20. Again, both relationships are curvilinear. However, in this case, unconfined compressive strength increases exponentially as mean hardness values increase. The hardness again provided a good index of rock properties as indicated by the relatively high r^2 values of 0.89 and 0.75 for the first and second study data sets, respectively. The two differing methods for obtaining the average hardness values are evident by the overlapping curves.

Peak Secant Modulus. Peak secant modulus (secant modulus at peak stress) data were available only for the first study. The relationship to mean hardness values is shown on Figure 21. As with the unconfined compressive strength data, the peak secant modulus data provide an upward curvilinear trend with an exponential function providing a best fit to the data points. The r^2 value for secant modulus was 0.88 for this data set as compared to the r^2 value of 0.89 for unconfined compressive strength for the same data set.

Peak Sonic Velocity. One final analysis, comparing peak sonic velocity (sonic velocity at peak stress) to mean hardness value is shown in Figure 22. This relationship, with r^2 values of 0.79 and 0.74, exhibits slightly more scatter as compared to the relationships for other rock properties. In addition, the trends appear to be linear rather than curvilinear. Again the juxtaposition of the curves for the two data sets reflects the different methods for obtaining the average hardness values.

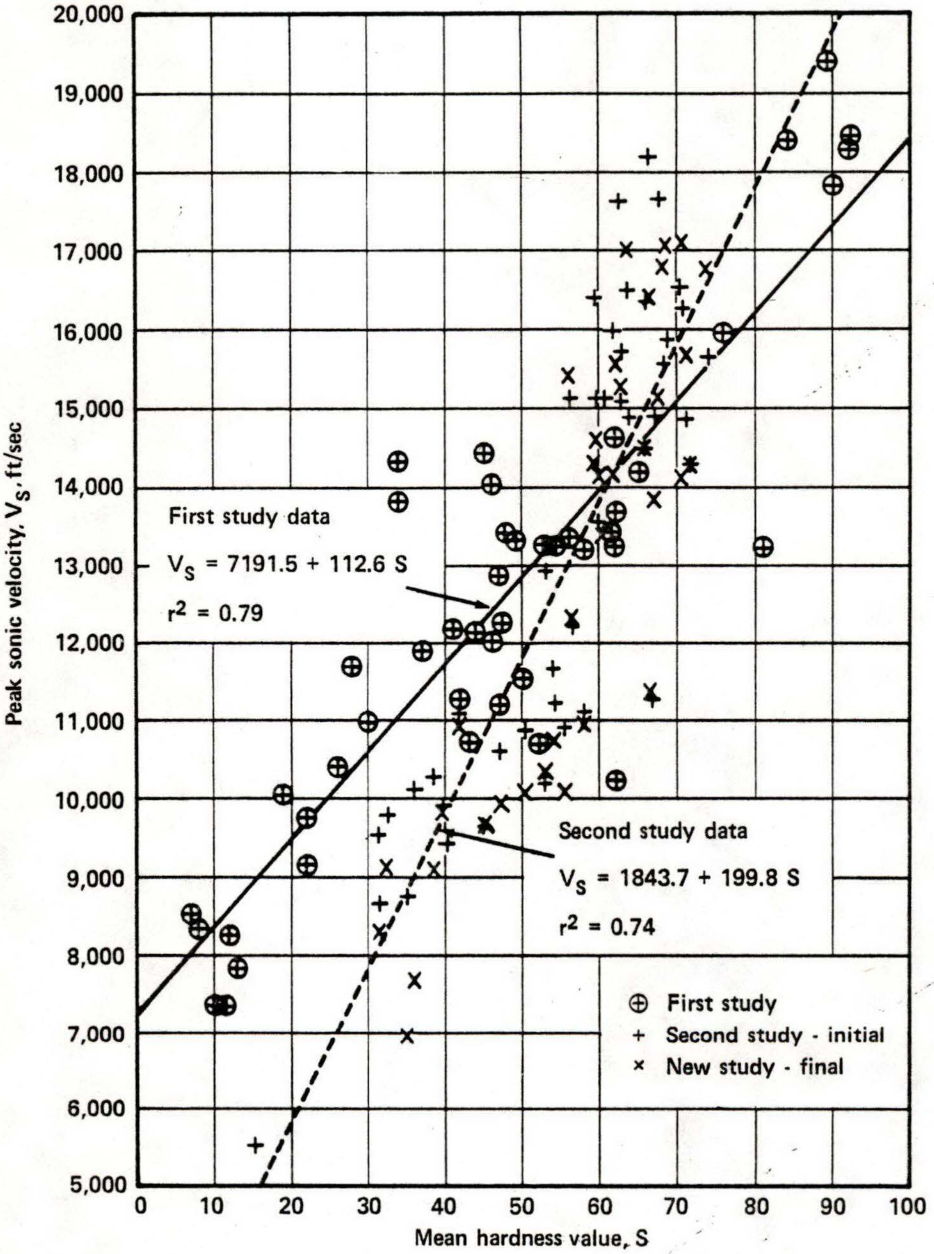


Fig. 21 Peak sonic velocity vs. mean hardness value

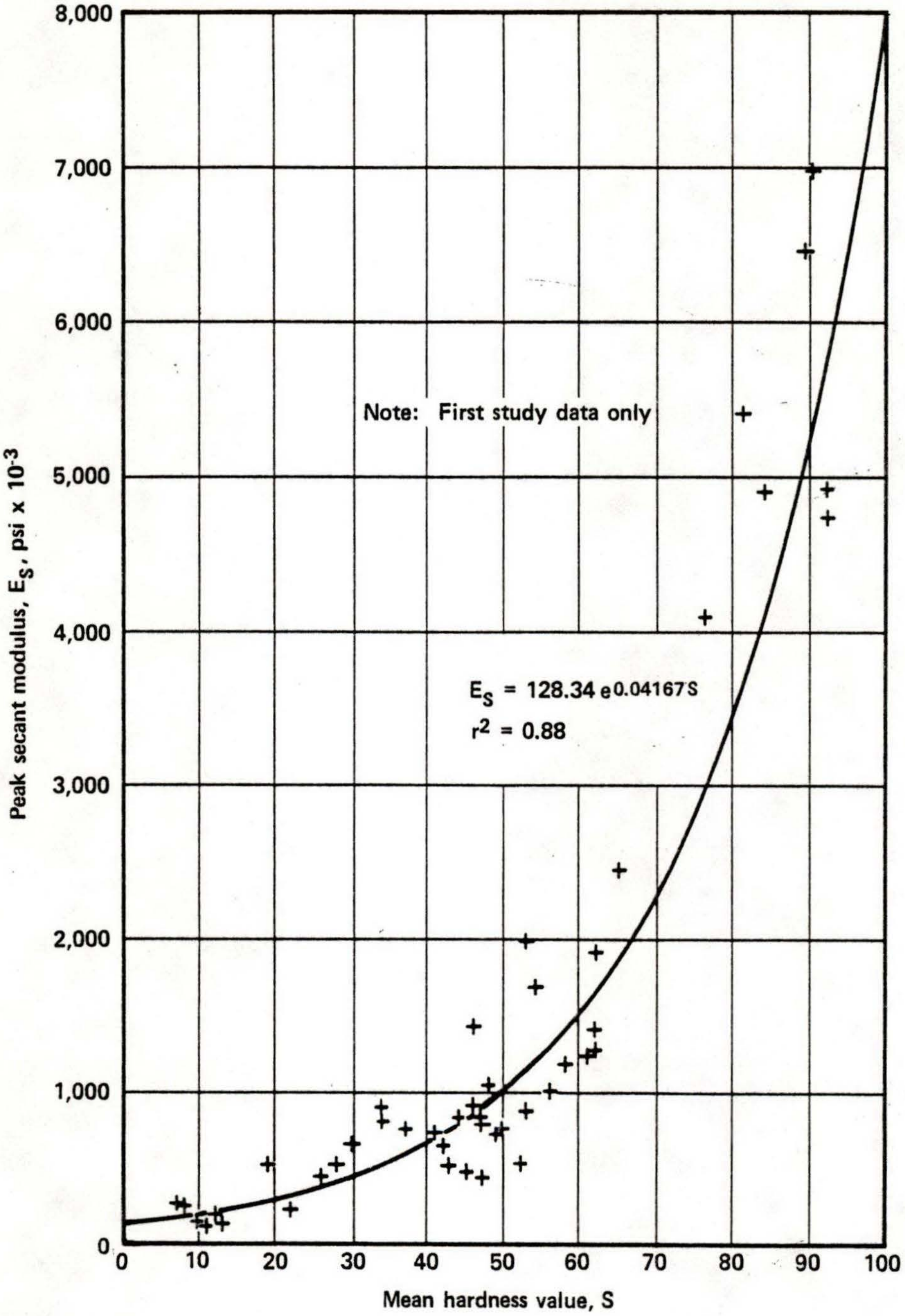


Fig. 22 Peak secant modulus vs. mean hardness value

SUMMARY AND CONCLUSIONS

Based on the data collected, it is apparent that the general principles and assumptions which formed the foundation of the research reported herein held true. In general, sonic velocity decreased with environmental cycling. However, the level of funding did not permit the extention of environmental cycling over a time sufficient to shed adequate light on the weathering of the rocks tested under the simulated environmental conditions.

Hardness test values were again proven to be a useful tool for the preliminary assessment of certain rock properties. The results appear to be consistent and the level of variability of the results appears to be acceptable, based on the results of statistical analysis.

Unconfined compressive strength test results were highly variable, even for samples taken from the same boring. This reflects inherent variability within the rock found at a particular location. Thus, extrapolation of unconfined compression test data should be done with caution, if at all.

RECOMMENDATIONS

Based on the results of the study reported herein, the following recommendations are in order:

1. A new study be funded, for a minimum period of four years, to assess the effects of environmental factors on the weathering of rocks of the Idaho Batholith.

2. Hardness tests should be an integral part of the new study. However to further minimize possible operator error, measurements should be by a self-reading scleroscope.

LIST OF REFERENCES

1. ASTM, 1971 Annual Book of ASTM Standards, ASTM, Philadelphia, 1971.

2. Clayton, J.L. and Arnold, J. F., "Practical Grain Size, Fracturing Density, and Weathering Classification of Intrusive Rocks of the Idaho Batholith," USDA Forest Service, General Technical Report INT-2, Ogden Utah, 1972.

3. Hampton, Delon, "Soil and Rock Properties in the Idaho Batholith, "Howard University Research Report, for U.S.D.A. Forest Service, January 1974.

4. Jensen, Frank and Finn, Larry, "Hydrologic Analysis of the Zena Creek Logging Study Area," prepared for U.S.D.A., Forest Service, Intermountain Region, 1966.

5. Reddick, H. W., and Miller, F. H., Advanced Mathematics for Engineers, John Wiley & Sons, Inc., New York, 1955, pp. 372-385.

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APPENDIX A

Summary of Sonic Velocity Data

Table A.1 Summary of Sonic Velocity Data

Test Type: Wet-Dry

Bore Hole No. 1

Sample No.	Test No.	Date	Number Cycles	Peak Velocity ft/sec
1	1	3/2/74	Initial	15,689
	2	3/9/74	4	18,515
	3	3/16/74	8	16,082
	4	3/24/74	12	15,896
	5	3/30/74	14	16,501
	6	7/13/74	32	15,786
	7	8/24/74	48	16,716
	8	11/2/74	82	15,301
	9	2/9/75	122	16,767
	10	6/28/75	177	15,245
5	1	3/2/74	Initial	15,073
	2	3/9/74	4	17,045
	3	3/16/74	8	15,179
	4	3/24/74	12	14,848
	5	3/30/74	14	12,991
	6	7/13/74	32	15,316
	7	8/24/74	48	15,203
	8	11/2/74	82	14,713
	9	2/9/74	122	15,204
	10	6/28/75	177	14,582
9	1	3/2/74	Initial	16,499
	2	3/9/74	4	16,975

Test Type: Wet-Dry

Bore Hole No. 1

Sample No.	Test No.	Date	Number Cycles	Peak Velocity ft/sec
9	1	3/16/74	8	15,558
	4	3/24/74	12	15,413
	5	3/30/74	14	13,212
	6	7/13/74	32	14,854
	7	8/24/74	48	15,915
	8	11/2/74	82	14,989
	9	2/9/75	122	15,324
	10	6/28/75	177	14,092
11	1	3/2/74	Initial	17,627
	2	3/9/74	4	17,971
	3	3/16/74	8	16,630
	4	3/24/74	12	16,043
	5	3/30/74	14	13,851
	6	7/13/74	32	16,016
	7	8/24/74	48	17,107
	8	11/2/74	82	16,109
	9	2/9/75	122	16,429
	10	6/28/75	177	15,111

Test Type: Freeze-Thaw

Bore Hole No. 1

Sample No.	Test No.	Date	Number Cycles	Peak Velocity ft/sec
2	1	3/2/74	Initial	15,822
	2	3/10/74	4	18,404
	3	3/16/74	7	14,429
	4	3/24/74	11	19,073
	5	3/30/74	14	18,559
	6	7/13/74	32	16,217
	7	8/24/74	48	18,148
	8	11/2/74	82	17,290
	9	2/9/75	122	18,229
	10	6/28/75	176	17,058
6	1	3/2/74	Initial	15,037
	2	3/10/74	4	16,650
	3	3/16/74	7	16,249
	4	3/24/74	11	17,272
	5	3/30/74	14	17,092
	6	7/13/74	32	15,057
	7	8/24/74	48	17,022
	8	11/2/74	82	15,511
	9	2/9/75	122	16,506
	10	6/28/75	176	14,975
8	1	3/2/74	Initial	16,465
	2	3/10/74	4	19,271
	3	3/16/74	7	18,201

Test Type: Freeze-Thaw

Bore Hole No. 1

Sample No.	Test No.	Date	Number Cycles	Peak Velocity ft/sec
8	4	3/24/74	11	19,433
	5	3/30/74	14	18,996
	6	7/13/74	32	16,299
	7	11/2/74	82	17,228
	8	2/9/75	122	17,766
	9	6/28/75	176	16,998
10	1	3/2/74	Initial	16,223
	2	3/10/74	4	18,482
	3	3/16/74	7	17,795
	4	3/24/74	11	18,309
	5	3/30/74	14	18,474
	6	7/13/74	32	16,118
	7	11/2/74	82	17,378
	8	2/9/75	122	17,526
	9	6/28/75	176	17,089

Test Type: Wet-Dry

Bore Hole No. 2

Sample No.	Test No.	Date	Number Cycles	Peak Velocity ft/sec
1	1	3/9/74	Initial	15,075
	2	3/16/74	4	14,025
	3	3/24/74	8	13,478
	4	3/30/74	10	12,049
	5	4/13/74	17	13,931
	6	7/13/74	28	13,836
	7	8/24/74	44	14,388
	8	11/2/74	78	14,188
	9	2/9/75	118	13,822
	10	6/28/75	173	13,389
3	1	3/9/74	Initial	14,262
	2	3/16/74	4	14,631
	3	3/24/74	8	14,734
	4	3/30/74	10	13,061
	5	4/13/74	17	15,215
	6	7/13/74	28	14,862
	7	8/24/74	44	15,551
	8	11/2/74	78	15,324
	9	2/9/75	118	15,268
	10	6/28/75	173	14,255
6	1	3/9/74	Initial	16,324
	2	3/16/74	4	14,910

Test Type: Wet-Dry

Bore Hole No. 2

Sample No.	Test No.	Date	Number Cycles	Peak Velocity ft/sec
6	3	3/24/74	8	14,579
	4	3/30/74	10	12,227
	5	4/13/74	17	14,705
	6	7/13/74	28	14,333
	7	8/24/74	44	14,728
	8	11/2/74	78	14,163
	9	2/9/74	118	14,702
	10	6/28/75	173	14,477

Test Type: Freeze-Thaw

Bore Hole No. 2

Sample No.	Test No.	Date	Number Cycles	Peak Velocity ft/sec
4	1	3/9/74	Initial	15,612
	2	3/16/74	3	17,234
	3	3/30/74	10	18,708
	4	7/13/74	28	16,121
	5	8/24/74	44	15,028
	6	11/2/74	77	17,443
	7	2/9/75	118	18,073
	8	6/28/75	174	16,747
5	1	3/9/74	Initial	15,535
	2	3/16/74	3	16,806
	3	3/24/74	7	18,313
	4	3/30/74	10	17,845
	5	7/13/74	28	15,592
	6	8/24/74	44	16,505
	7	11/2/74	77	16,473
	8	2/9/75	118	17,112
	9	6/28/75	174	16,769
7	1	3/9/74	Initial	14,825
	2	3/16/74	3	15,647
	3	3/24/74	7	17,080
	4	3/30/74	10	16,939
	5	7/13/74	28	15,042
	6	11/2/74	77	15,499

Test Type: Freeze-Thaw

Bore Hole No. 2

Sample No.	Test No.	Date	Number Cycles	Peak Velocity ft/sec
7	7	2/9/75	118	16,001
	8	6/28/75	174	15,644

Test Type: Wet-Dry

Bore Hole No. 3

Sample No.	Test No.	Date	Number Cycles	Peak Velocity ft/sec
2	1	3/24/74	Initial	15,936
	2	3/30/74	3	15,894
	3	7/13/74	21	15,440
	4	8/24/74	37	16,639
	5	11/2/74	71	15,090
	6	2/9/75	111	14,829
	7	6/28/75	166	14,131
3	1	3/24/74	Initial	17,592
	2	3/30/74	3	17,737
	3	7/13/74	21	16,850
	4	8/24/74	37	17,468
	5	11/2/74	71	17,029
	6	2/9/75	111	16,504
	7	6/28/75	166	15,546
4	1	3/24/74	Initial	14,849
	2	3/30/74	3	14,795
	3	7/13/74	21	14,531
	4	8/24/74	37	14,954
	5	11/2/74	71	14,303
	6	2/9/75	111	14,228
	7	6/28/75	166	13,821

Test Type: Freeze-Thaw

Bore Hole No. 3

Sample No.	Test No.	Date	Number Cycles	Peak Velocity ft/sec
1	1	3/24/74	Initial	18,198
	2	3/30/74	3	19,059
	3	7/13/74	21	18,035
	4	11/2/74	71	19,104
	5	2/9/75	111	18,614
	6	6/28/75	165	16,385
5	1	3/24/74	Initial	13,518
	2	3/30/74	3	14,529
	3	7/13/74	21	13,404
	4	8/24/74	37	15,119
	5	11/2/74	71	13,884
	6	2/9/75	111	14,075
	7	6/28/75	165	14,124

Test Type: Wet-Dry

Bore Hole No. 4

Sample No.	Test No.	Date	Number Cycles	Peak Velocity ft/sec
1	1	3/24/74	Initial	10,112
	2	3/30/74	3	10,138
	3	7/13/74	21	8,779
	4	8/24/74	37	8,879
	5	11/2/74	71	8,023
	6	2/9/74	111	7,941
	7	6/28/75	165	7,676
8	1	3/24/74	Initial	8,730
	2	3/30/74	3	8,758
	3	7/13/74	21	7,857
	4	8/24/74	37	7,481
	5	11/2/74	71	6,974
	6	2/9/74	111	7,114
	7	6/28/75	165	6,921
11	1	3/24/74	Initial	10,260
	2	3/30/74	3	9,987
	3	7/13/74	21	9,772
	4	8/24/74	37	9,913
	5	11/2/74	71	9,658
	6	2/9/75	111	9,866
	7	6/25/75	165	9,103

Test Type: Freeze-Thaw

Bore Hole No. 4

Sample No.	Test No.	Date	Number Cycles	Peak Velocity ft/sec
2	1	3/24/74	Initial	9,775
	2	3/30/74	3	10,535
	3	7/13/74	21	9,283
	4	11/2/74	71	9,600
	5	2/9/75	111	9,774
	6	6/28/75	165	9,137
3	1	3/24/74	Initial	9,903
	2	3/30/74	3	10,260
	3	7/13/74	21	9,579
	4	8/24/74	37	10,669
	5	11/2/74	71	9,961
	6	2/9/75	111	9,784
	7	6/28/75	165	9,830
10	1	3/24/74	Initial	11,059
	2	3/30/74	3	10,941
	3	7/13/74	21	10,385
	4	11/2/74	71	9,513
	5	2/9/75	111	11,027
	6	6/28/75	165	10,939

Test Type: Wet-Dry

Bore Hole No. 5

Sample No.	Test No.	Date	Number Cycles	Peak Velocity ft/sec
1	1	7/13/74	Initial	11,645
	2	8/24/74	16	11,467
	3	11/2/74	50	10,640
	4	2/9/75	90	11,038
	5	6/28/75	145	10,722
9	1	7/13/74	Initial	16,358
	2	8/24/74	16	16,320
	3	11/2/74	50	13,867
	4	2/9/75	90	15,065
	5	6/28/75	145	14,283
11	1	7/13/74	Initial	12,675
	2	8/24/74	16	13,162
	3	11/2/74	50	12,188
	4	2/9/75	90	12,279
	5	6/28/75	145	12,010

Test Type: Freeze-Thaw

Bore Hole No. 5

Sample No.	Test No.	Date	Number Cycles	Peak Velocity ft/sec
4	1	7/13/74	Initial	12,182
	2	11/2/74	50	12,441
	3	2/9/75	90	12,594
	4	6/28/75	144	12,292
8	1	7/13/74	Initial	15,101
	2	8/24/74	16	15,900
	3	11/2/74	50	15,411
	4	2/9/74	90	15,630
	5	6/28/75	144	15,397
10	1	7/13/74	Initial	12,873
	2	11/2/74	50	14,030
	3	2/9/75	90	13,570
	4	6/28/75	144	13,223

Test Type: Wet-Dry

Bore Hole No. 7

Sample No.	Test No.	Date	Number Cycles	Peak Velocity ft/sec
1	1	7/13/74	Initial	10,867
	2	8/24/74	16	11,104
	3	11/2/74	50	10,668
	4	2/9/75	90	10,696
	5	6/28/75	145	10,087
2	1	7/13/74	Initial	10,900
	2	8/24/74	16	10,333
	3	11/2/74	50	10,492
	4	2/9/75	90	10,385
	5	6/28/75	145	10,052
4	1	7/13/74	Initial	8,636
	2	8/24/74	16	8,599
	3	11/2/74	50	8,748
	4	2/9/75	90	8,545
	5	6/28/75	145	8,299

Test Type: Freeze-Thaw

Bore Hole No. 7

Sample No.	Test No.	Date	Number Cycles	Peak Velocity ft/sec
1	1	7/13/74	Initial	11,198
	2	8/24/74	16	11,745
	3	11/2/75	50	10,162
	4	2/9/75	90	12,022
	5	6/28/75	144	11,612
6	1	7/13/74	Initial	9,655
	2	11/2/74	50	9,865
	3	2/9/75	90	9,829
	4	6/28/75	144	9,632

Test Type: Wet-Dry

Bore Hole No. 11

Sample No.	Test No.	Date	Number Cycles	Peak Velocity ft/sec
3	1	7/13/74	Initial	11,248
	2	8/24/74	16	11,778
	3	11/2/74	50	11,459
	4	2/9/75	90	11,366
	5	6/28/75	145	10,926
7	1	7/13/74	Initial	10,585
	2	8/24/74	16	10,406
	3	11/2/74	50	10,406
	4	2/9/75	90	10,406
	5	6/28/75	145	9,926
8	1	7/13/74	Initial	10,137
	2	8/24/74	16	10,492
	3	11/2/74	50	10,126
	4	2/9/75	90	10,416
	5	6/28/75	145	10,009

Test Type: Freeze-Thaw

Bore Hole No. 11

Sample No.	Test No.	Date	Number Cycles	Peak Velocity ft/sec
2	1	7/13/74	Initial	11,242
	2	11/2/74	50	11,520
	3	2/9/75	90	12,085
	4	6/28/75	144	11,333
6	1	7/13/74	Initial	10,177
	2	11/2/74	50	10,627
	3	2/9/75	90	10,549
	4	6/28/75	144	10,332
9	1	7/13/74	Initial	11,069
	2	8/24/74	16	12,136
	3	11/2/74	50	10,870
	4	2/9/75	90	11,237
	5	6/28/75	144	10,942

Type Test

Borehole No.	Sample No.	Date	Test Type	Cycles	Velocity	Remarks
7	1	3/2/74	F-T	-	-	
		5/26/75	F-T	-	14,627	
		8/30/75	F-T	-	14,224	
3	3	3/2/74	W-D	-	-	
2	2	3/9/74	F-T	-	14,451	
		5/26/75	F-T	-	13,846	
		8/30/75	F-T	-	13,419	
4	5	5/26/75	Control	-	9,401	
		8/30/75	Control	-	9,232	
5	7	5/26/75	Control	-	14,841	
7	4	5/26/75	Control	-	10,012	
		8/30/75	Control	-	10,879	
8	1	5/26/75	Control	-	9,517	
		8/30/75	Control	-	9,228	
10	2	5/26/75	Control	-	5,501	
		8/30/75	Control	-	5,668	
11	1	5/26/75	Control	-	10,871	
		8/30/75	Control	-	11,955	